STUDY OF MULTI-KW SOLAR ARRAYS FOR EARTH ORBIT APPLICATIONS MIDTERM PERFORMANCE REVIEW

NASA-MSFC CONTRACT NAS8-32988
JULY 26, 1979

(NASA-CR-161467) STUDY OF MULTI-kW SOLAR ARRAYS FOR EARTH ORBIT APPLICATIONS: MIDTERM PERFORMANCE REVIEW (Rockwell International Corp., Huntsville, Ala.) 98 p HC A05/MF A01 CSCL 10A G3/44

N80-24798

Unclas
22523

Satellite Systems Division
Space Systems Group
Rockwell International

79SSD03730

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BRIEFING OUTLINE

OVERVIEW

- OBJECTIVES
- APPROACH
- GROUNDRULES/REQUIREMENTS

– S.J. NALBANDIAN

DESIGN CONCEPTS

- SOLAR ARRAY/CELL TECHNOLOGY
  – S.J. NALBANDIAN
- CONCENTRATOR CONCEPTS
  – E.P. FRENCH
- CONFIGURATION TRADES
  - DEPLOYMENT MODES
  - PLANAR
  - CONCENTRATOR

  –J.A. MENAGER

ON-ORBIT MAINTAINABILITY

- SHUTTLE CAPABILITY
- MAINTENANCE TRADES

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SUMMARY

- PRELIMINARY CONCLUSIONS
- PLANNED ACTIVITIES

–S.J. NALBANDIAN

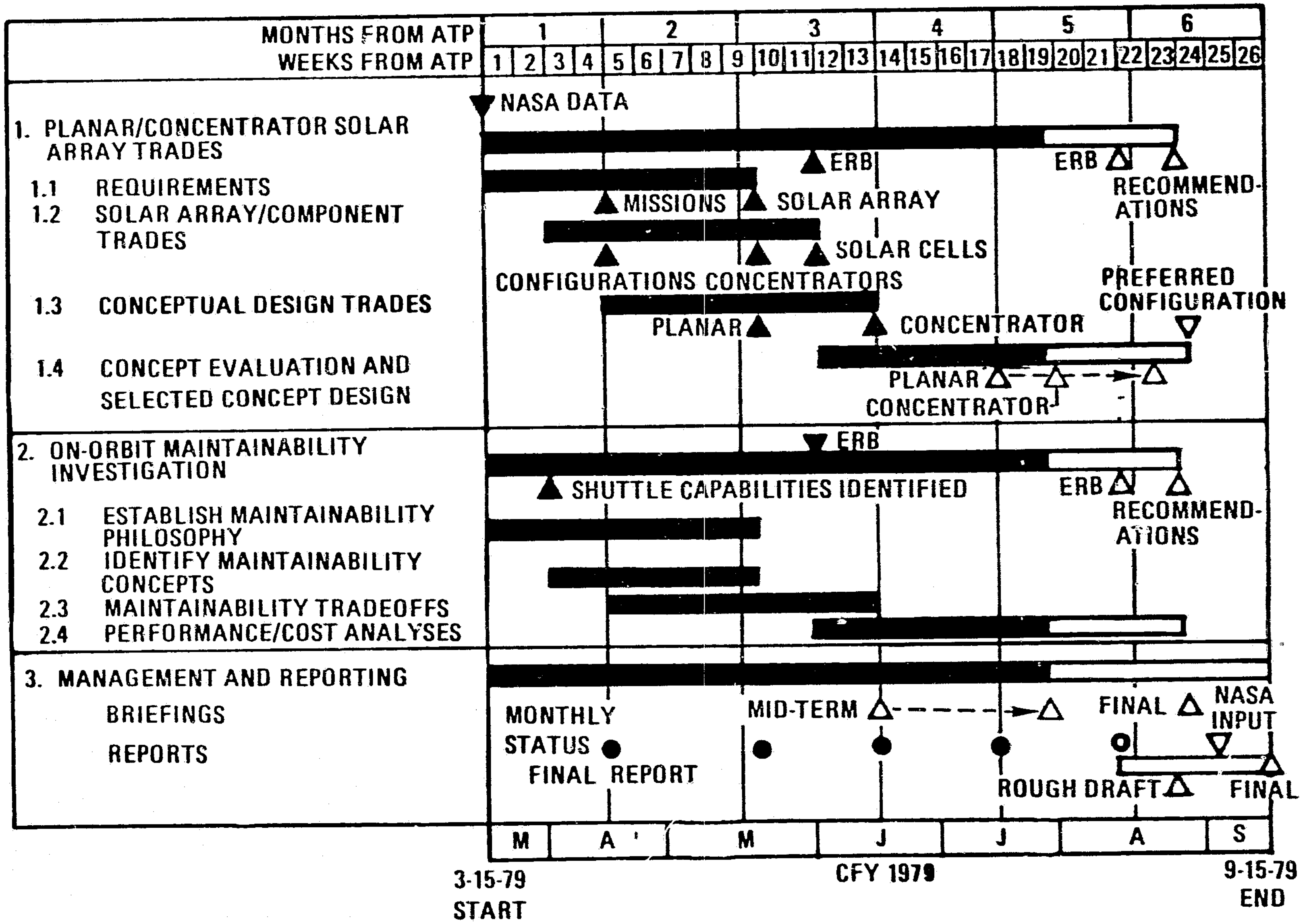
STUDY OBJECTIVES

- IDENTIFY SOLAR ARRAY CONCEPTS CAPABLE OF PROVIDING 300 KW TO 1000 KW IN LOW EARTH ORBIT APPLICATIONS IN THE 1987 TIME PERIOD AT AN ARRAY RECURRING COST $\leq$ \$30 PER WATT.
  - INVESTIGATE PLANAR AND CONCENTRATOR ARRAY CONCEPTS
  - EVALUATE SILICON AND GALLIUM ARSENIDE SOLAR CELL APPLICABILITY
  - ASSESS ON-ORBIT MAINTENANCE BY SHUTTLE AND EVA REPLACEMENT OF LIFE-LIMITING COMPONENTS

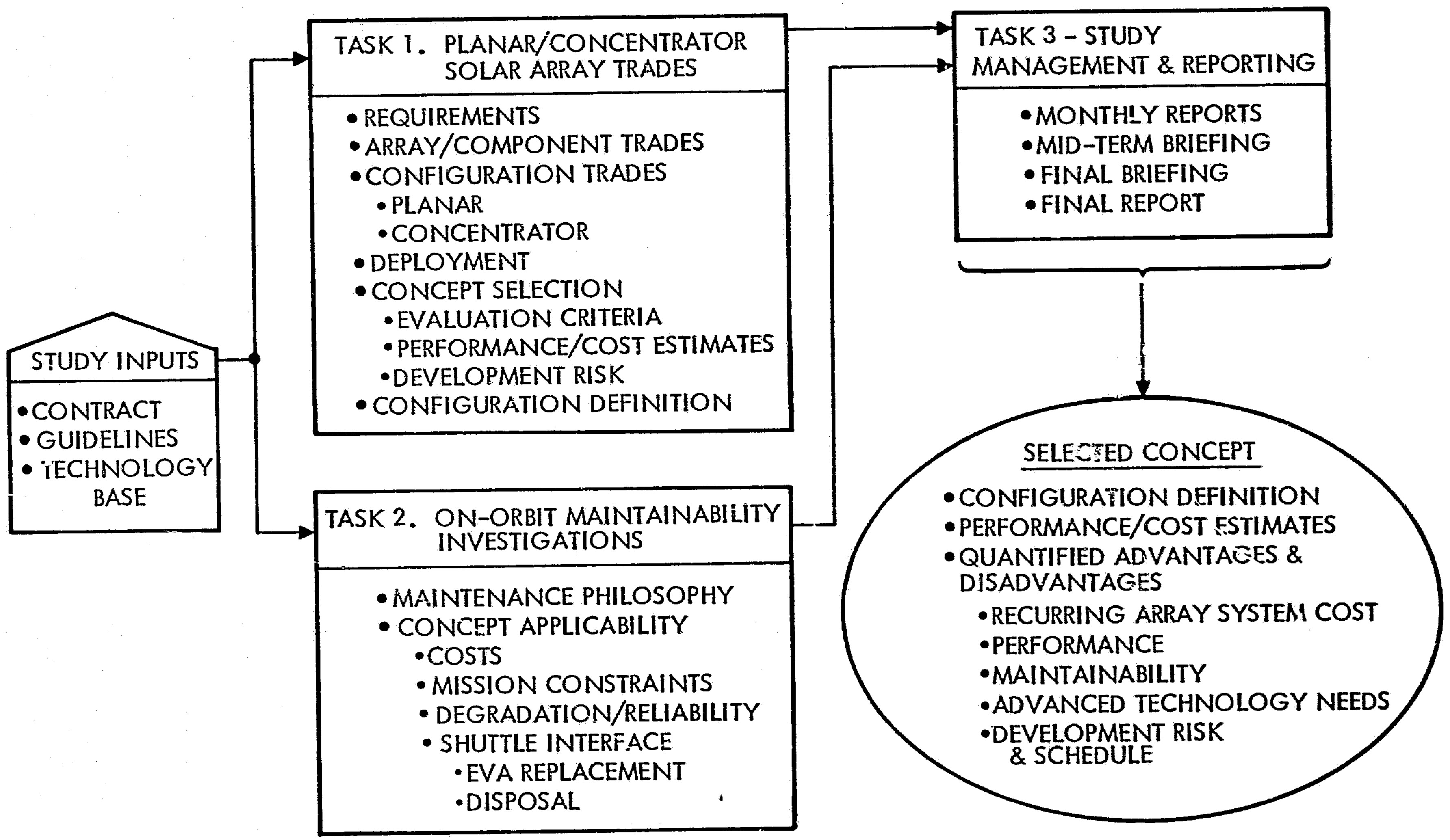
GROUND RULES/ASSUMPTIONS

- CONFIGURATIONS COMPATIBLE WITH SHUTTLE ORBITER CARGO COMPARTMENT AND ON-ORBIT MAINTENANCE OPERATIONS
  - SPACE SHUTTLE PAYLOAD ACCOMMODATIONS (JSC-07700, VOL. XIV, REV. F)
  - SHUTTLE EVA DESCRIPTION AND DESIGN CRITERIA (JSC-10615)
- SPECIFIC POWER GOAL GOVERNED BY TRANSPORTATION COST PENALTIES AND REASONABLE EXTENSION OF STATE OF ART
- ALL COSTS ADJUSTED FOR 1979 DOLLARS
  - SHUTTLE TRANSPORTATION SYSTEM REIMBURSEMENT GUIDE (JSC-11802)
  - RECURRING SYSTEM COSTS DO NOT INCLUDE DESIGN, GROUND SUPPORT OPERATIONS, AND INITIAL LAUNCH COSTS
- MISSION REQUIREMENT TYPIFIED BY LARGE EARTH ORBITING SPACE PLATFORM (POST 1987)
  - LOW EARTH ORBITS ($\sim$300 KM TO 600 KM)
  - RADIATION
  - ORIENTATION
  - TEMPERATURE
  - ON-ORBIT MAINTAINABILITY
  - RECOVERY/DISPOSAL

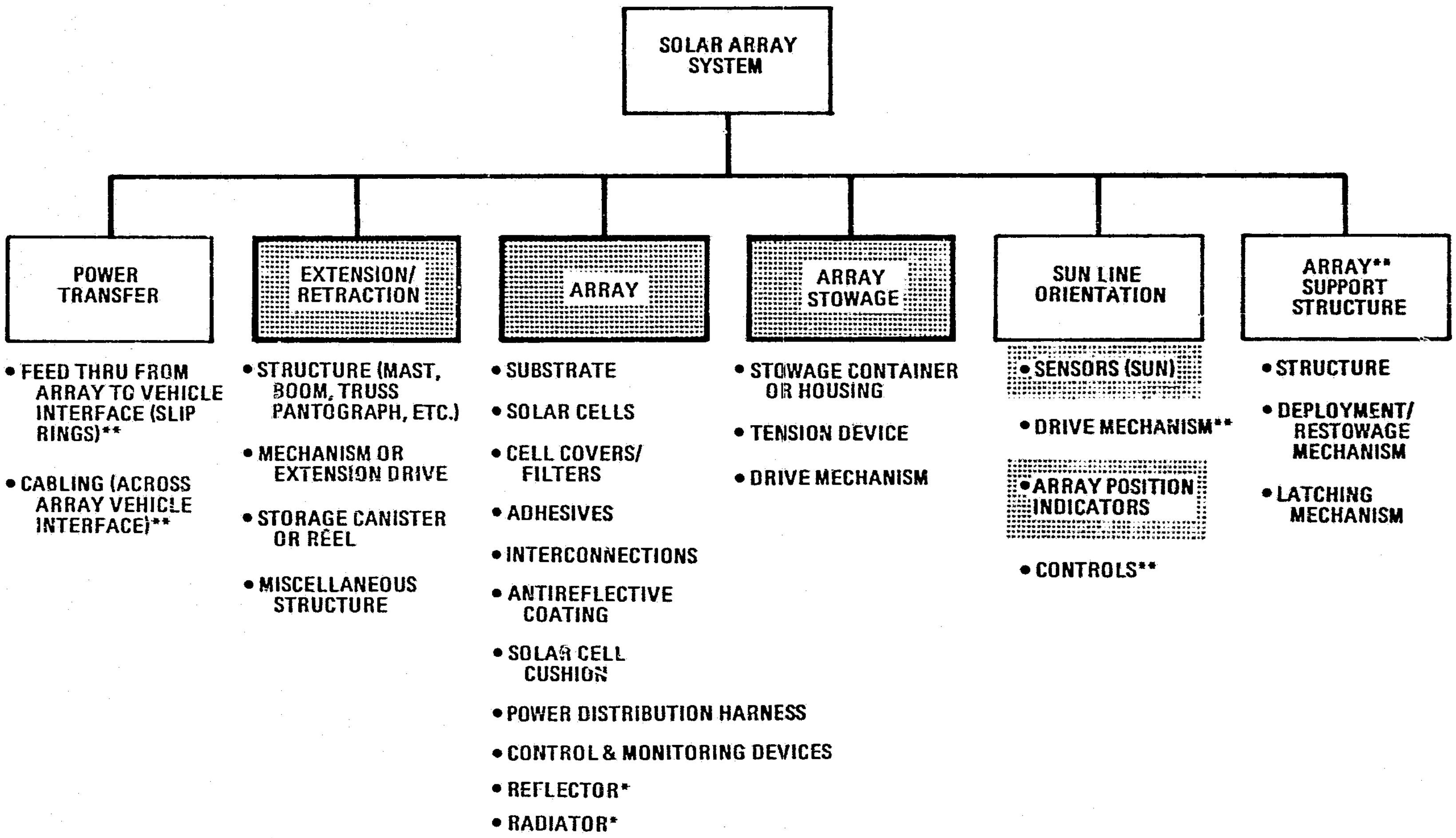
MULTI-KW SOLAR ARRAYS STUDY SCHEDULE



STUDY APPROACH METHODOLOGY

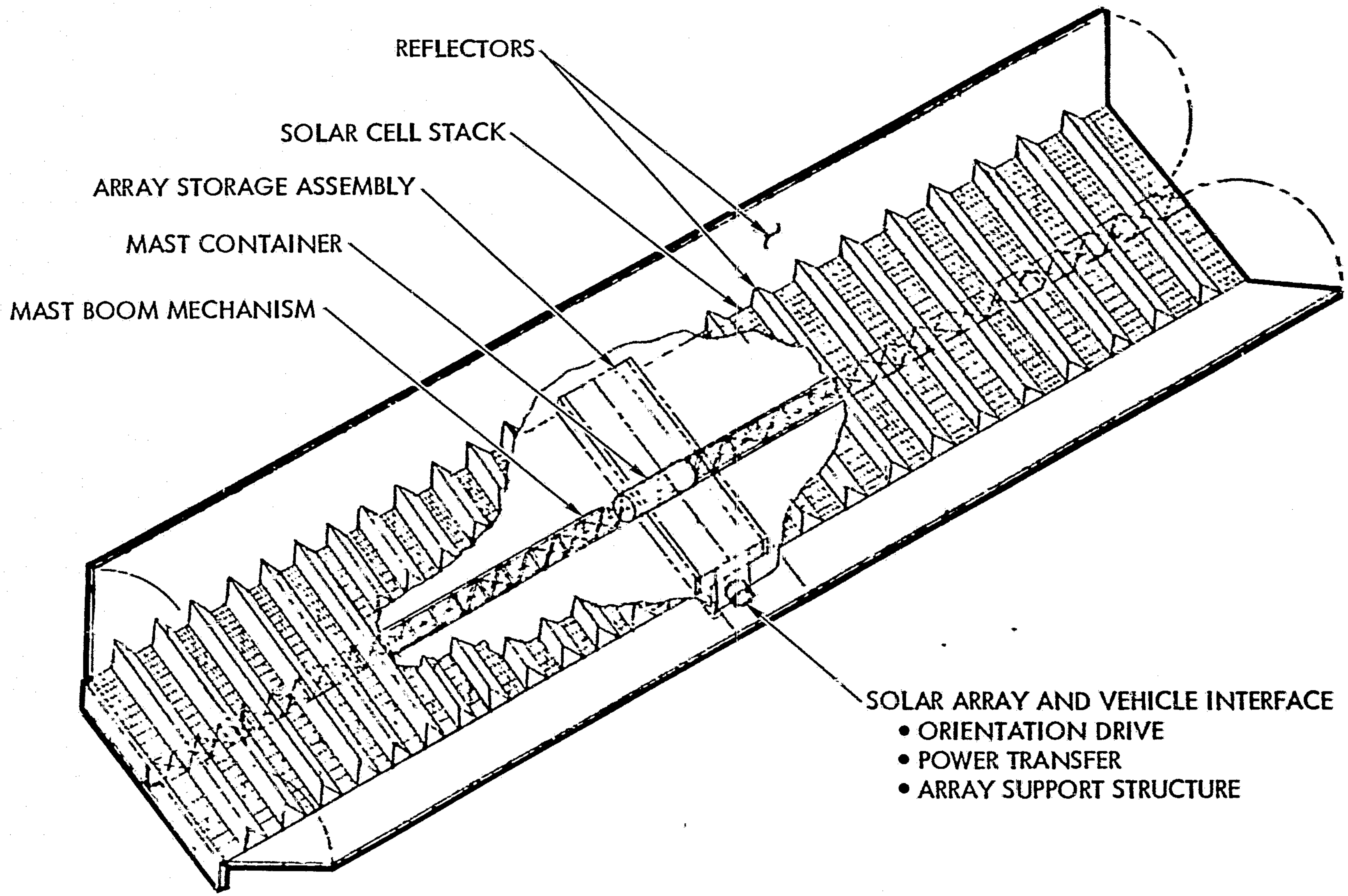


SOLAR ARRAY WEIGHT AND COSTING ELEMENTS



*FOR CONCENTRATING ARRAYS ONLY
**WEIGHT & COST OF THESE ITEMS ARE NOT CHARGEABLE IN DETERMINING SPECIFIC POWER & COST OF ARRAY

SOLAR ARRAY NOMENCLATURE



KEY ISSUES

- $30 PER WATT OR LESS GOAL FOR SYSTEM RECURRING COST

  300 KW TO 1000 KW ARRAY SYSTEM

- LIFETIME DETERMINED BY TECHNOLOGY OBSOLESCENCE

- APPLICATION IN LOW EARTH ORBIT
  - RADIATION LEVELS
  - TEMPERATURE PROFILE
  - DEGRADATION EFFECTS
  - RANDOM FAILURE EFFECTS

- MAINTENANCE COST
  - MANNED VERSUS UNMANNED
  - DEGRADATION EFFECT (UNIFORM OVER ENTIRE SOLAR CELL PANEL)
  - MAINTENANCE DESIGN COMPLEXITY
  - SHUTTLE TRANSPORTATION & ON-ORBIT OPERATIONS (MINIMUM CHARGE)
  - LIFE CYCLE ENERGY COST

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SOLAR ARRAY TECHNOLOGY COMPARISONS

PARAMETER	MSFC SEPS*	MSFC PEP	JPL/MSFC ULTRA LOW-MASS STUDY: LOCKHEED PLANAR	JPL/MSFC ULTRA LOW-MASS STUDY: LOCKHEED CONCENT.	JPL/MSFC ULTRA LOW-MASS STUDY: GENERAL ELECTRIC BASELINE	JPL/MSFC ULTRA LOW-MASS STUDY: GENERAL ELECTRIC OPTIONAL	MSFC ROCKWELL/ SPS STUDY	MSFC MULTI-kW STUDY
CONCENTRATION RATIO	1.0	1.0	1.0	2.0**	4.66***	4.66***	~2	TBD
POWER (kW), BOL	25	32.9	120	182	60 (WITHOUT CONCENTR)	60 (WITHOUT CONCENTR)	5×10⁶	300-1000
VOLTAGE (V)	200-400	120	327	200-400	200-400	200-400	43.8×10³	TBD
ASPECT RATIO, EACH WING	7.75	9.8	5	4.9	4	3.3	2	
POWER TO SIZE (W/m²)	101	113	135	237	94.4 (WITH-OUT CONCENT)	114.9 (WITH-OUT CONCENTR)	314	
CELL MATERIAL	200 µm Si	200 µm Si	75 µm Si	125 µm Si	50 µm Si	150 µm Si	6.3-9 GaAs	
COVER MATERIAL	150 µm FS µSHEET	150 µm FS	25 µm	75 µm CMS	75 µm	75 µm	20 µm Al_2O_3	
CELL TO COVER ADHESIVE	50 µm, DC 93500	50 µm, DC 93500	RTV655		RTV655	RTV655	—	
CELL EFFICIENCY (%)	11.4	12.8	12.5	13.0	11.1	13.5	17.6	
TOTAL WEIGHT (kg)	380	435	500	784	773	795	7.69×10⁶	
TOTAL AREA (m²)	250	290	921	386 (BL)	635 (BLANKET)	522 (BLANKET)	15.92×10⁶	
POWER TO WEIGHT (W/kg)	66	75	240	232	77.6	75.5	650	
SUBSTRATE + CELLS (kg/m²)	0.99	0.95	0.31	0.27			0.25	
STORAGE + SUPPORT STRUCTURE (kg/m²)	0.18	0.25	0.22	0.61	0.23	0.3	0.12	
DEPLOYMENT (kg/m²)	0.35	0.3	0.03	0.04			—	
REFLECTORS (kg/m²)	—	—	—	0.1	0.12	0.14	0.036	TBD
RECURRING COST ($/W)	200-300	~275	~300	~150	~300	~150	0.5-1.0	≤30
TOTAL (kg/m²)	1.52	1.5	0.56	1.02	0.35	0.44	0.41	TBD

FS - FUSED SILICA µSHEET - MICROSHEET CMS - CERIA DOPED MICROSHEET
*SEPS TECHNOLOGY—CURRENT SEPS DESIGN REQUIRES 25 KW EOL & 12.8% CELLS

** EFFECTIVE CR ~ 1.9
*** EFFECTIVE CR ~ 3.2

SOLAR CELL TECHNOLOGY

MATERIAL	TYPE	SIZE (cm)	THICKNESS (μm)	EFFICIENCY AT 1 AU 28°C AMO ( ) PRESENT	PROJECTION ♦	STATUS OF AVAILABILITY	POTENTIAL FUTURE AVAILABILITY	RELATIVE** COST OF CELL POWER
Si	SPACE PROVEN	2×2 TO 2×6	200-300	12-15	17	PRODUCTION	SPECTRALAB, OCLI	15
	THIN	2×2	50	11	12.5	PRE-PRODUCTION	SOLAREX	
	THIN WRAP-AROUND	2×4	75	12	13	MADE IN R&D	SPECTRALAB, OCLI	39-45
			125	16	13.5	MADE IN R&D		25
			200	11.4	14	PRODUCTION		16
	LARGE AREA	5×5	50-350	12	15	PROJECTION	OCLI	4-7
	TERRESTRIAL	7.6 DIA.	375	11	14	PRODUCTION	OCLI	1**
GaAs	HUGHES-LPE	2×2	300	16	18	PRE-PRODUCTION	SPECTROLAB	
	HUGHES-LPE	2×4	150	—	18	DEVELOPMENT GOAL	SPECTROLAB	5-120
	ROCKWELL-LPE	1 DIA.	250	17.3	20	MADE IN R&D	ROCKWELL	
	ROCKWELL-CVD	0.29 cm²	250	12.8*		MADE IN R&D	ROCKWELL	0.5-5
	ROCKWELL CVD	2×4	25	—	18	DEVELOPMENT GOAL	ROCKWELL	
CdS	Cu_xS/CdS			4.8 (AMI)	10	MADE IN R&D	—	
a-Si	SCHOTTKY BARRIER		1 μm ON SUBSTRATE	5.5 (AMI)	12	MADE IN R&D	RCA, ECD	
MULTIPLE MATERIALS	TANDEM				25-30	PROOF OF PRINCIPLE	ROCKWELL, RESEARCH TRIANGLE INST.	

NOTES:

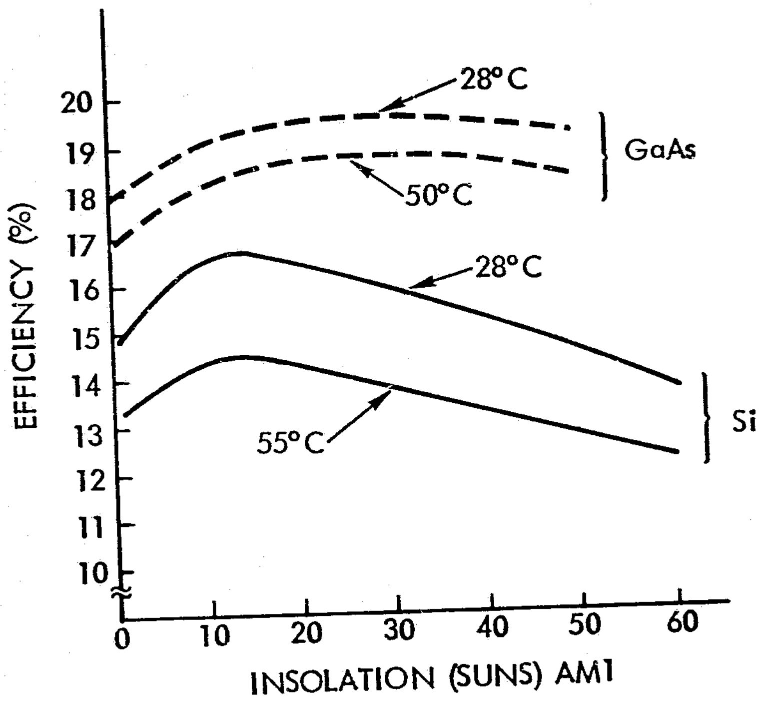
LPE - LIQUID PHASE EPITAXIAL
CVD - CHEMICAL VAPOR DEPOSITION
a-Si - AMORPHOUS SILICON

♦ 1987 PROJECTION

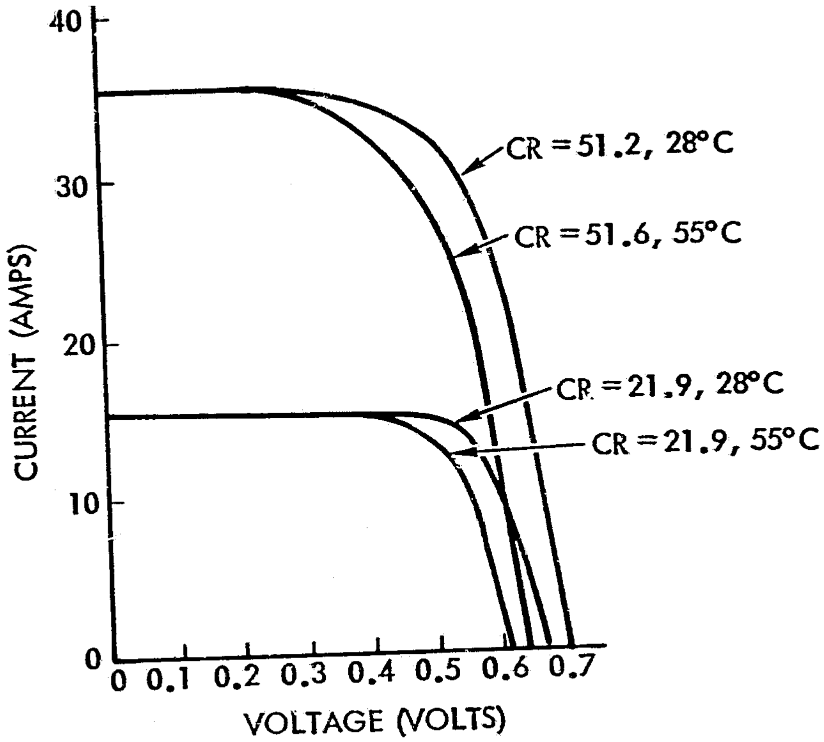
* NO ANTI-REFLECTIVE COATING

**BASED ON \$8/W FOR SPACE QUALITY TERRESTRIAL TYPE CELL.

CONCENTRATING SOLAR CELL PERFORMANCE



– – – – – ROCKWELL DATA



OCLI DATA ON 5.7-CM DIAMETER Si CONCENTRATING CELL

SOLAR CELL COVERS (DISCRETE)

MATERIAL		AVAILABILITY		DEVELOPMENT PROBLEMS	ADVANTAGE	DISADVANTAGE	COMMENTS
COVER	ADHESIVE	STATUS	FUTURE				
FS	DC-93500	PRODUCTION	NO RISK	NONE	SPACE PROVEN, STABLE	EXPENSIVE, BRITTLE	THICKNESS LIMITATION MINIMUM 150 µm FOR FS AND 25-50 µm FOR ADHESIVE
FS	FEP	PRODUCTION	LOW RISK	DELAMINATION	LOWER COSTS, NO NEED FOR UV FILTER	DEVELOPMENT PROBLEM, FEP	
CMS	DC-93500	PRODUCTION	NO RISK	NONE	SPACE PROVEN, STABLE, NO UV FILTER REQ'D. LOWER COST, HIGHER STRENGTH THAN FS.	SLIGHTLY LOWER RESISTANCE TO HIGH LEVELS OF PARTICLE RADIATION THAN FS	5% CERIA PROVIDES UV PROTECTION FOR ADHESIVE & IMPROVES RESISTANCE TO DARKENING DUE TO PARTICLE RADIATION. THICKNESS LIMIT MIN. 75 µm FOR CMS
MS	DC-93500	PRODUCTION	NO RISK	NONE	SPACE PROVEN, LOWEST COST OF DISCRETE INORGANIC COVERS	LESS STABLE THAN THE ABOVE	THICKNESS LIMIT MIN. 75 µm FOR MS

NOTE:

FS - FUSED SILICA, CORNING GLASS 7940

CMS - CERIUM-DOPED MICROSHEET, CORNING GLASS 0212
CERIA-STABILIZED MICROSHEET, PILKINGTON PERKIN-ELMER

MS - MICROSHEET, CORNING GLASS 0211

SOLAR CELL COVERS (INTEGRAL)

MATERIAL	AVAILABILITY STATUS	AVAILABILITY FUTURE	DEVELOPMENT PROBLEMS	ADVANTAGE	DISADVANTAGE	COMMENTS
QUARTZ	DEVELOPMENT	HIGH RISK	INDUCED STRESSES, HIGH COST	NO MINIMUM THICKNESS LIMIT	DEVELOPMENT PROBLEMS	
SYNTHETIC SAPPHIRE	PRODUCTION	LOW RISK	LOW RISK	SUITABLE AS SUBSTRATE AND COVER FOR GaAs CELLS, THUS REDUCES COST & WEIGHT OF GaAs	HIGH COST	SUITABLE FOR USE WITH GaAs CELL
RTV 655	PRODUCTION	RISK	DEGRADATION IN SPACE	LIGHT, LOW COST	DEVELOPMENT PROBLEMS	ACCELERATED UV TEST SHOWS SEVERE DEGRADATION ~20%. TESTING AT LOWER RATES MAY GIVE ACCEPTABLE RESULTS
SPRAYLON	DEVELOPMENT	RISK	DEGRADATION IN SPACE	LIGHT, LOW COST	DEVELOPMENT PROBLEMS	LIMITED RESISTANCE TO UV & CHARGED PARTICLE RADIATION. MAY BE ACCEPTABLE FOR LEO.*
FEP	PRODUCTION	RISK	DEGRADATION IN SPACE	LIGHT, LOW COST	DEVELOPMENT PROBLEMS	AT LOW THICKNESS (<50 μm) ε IS LOW, APPROACHING CELL ε ≈.4. AT HIGH THICKNESS (>125 μm) ε ≈.85.

NOTE: RTV 655 - SILICONE ELASTOMER, GE; SPRAYLON - LMSC NAME FOR ESSENTIALLY FEP THAT IS APPLIED BY SPRAYING; FEP - FEP TEFLON, FLUORINATED ETHYLENE PROPYLENE, DUPONT.

*SERIOUS DEGRADATION (>40%) WAS FOUND AFTER HIGH PARTICLE RADIATION EXPOSURE (>2 YR AT SYNCHRONOUS ORBIT) BUT PRIOR TO REACHING THIS DOSAGE APPEARED ACCEPTABLE..

SELECTED DESIGN FACTORS

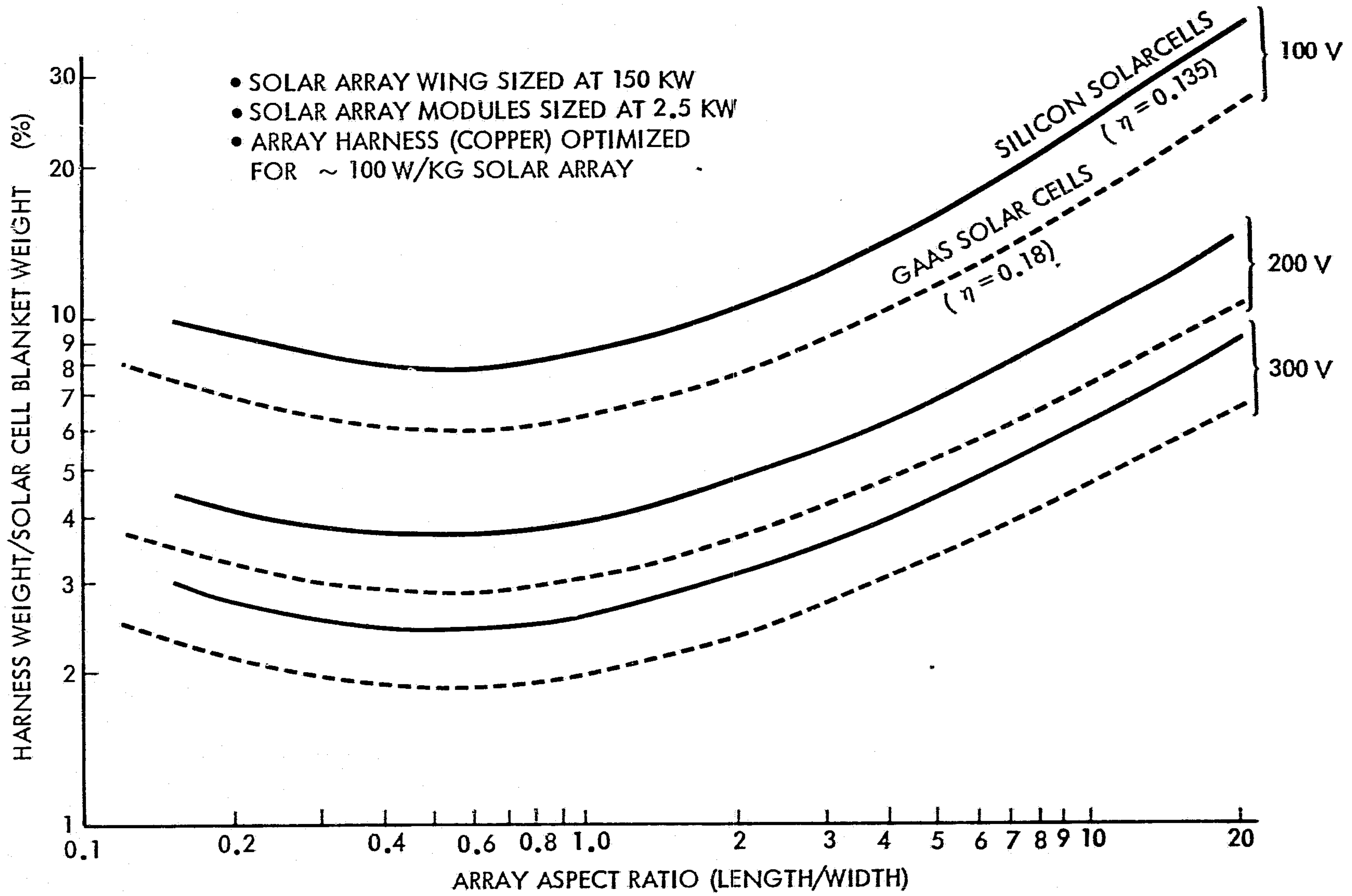
PARAMETER	PLANAR	CONCENTRATOR
SOLAR INPUT ON CELLS	1353 W/m^2	1353 W/m^2 x REFLECTOR XCR
CONCENTRATION RATIO (CR)	1	≤ 5
REFLECTOR EFFICIENCY	1	0.87 PER REFLECTION
SOLAR CELL EFF. (AMO, 28°C)		
η - SILICON	SPACE, 0.15; TERRESTRIAL, 0.14	0.15
η - GaAs	0.18	0.18
U.V.	0.98	0.98
ARRAY VOLTAGE	200 V - 300 V	200 V - 300 V
HARNESS	0.96	0.96
FAB & ASSEMBLY	0.97	0.97
PACKING FACTOR CELLS	0.85 - 0.98	0.9 - 0.96
PACKING FACTOR CELL GROUPS	0.9	0.9
ORIENTATION (±1 DEG) (MINIMUM REFLECTOR SIZE)	1	0.98 (CR-2) - 0.85 (CR-5)
TEMPERATURE > 0°C		
SILICON (MAX. POWER EFFICIENCY)	-0.0006 PER °C	-0.0006 PER °C
GaAs (MAX. POWER EFFICIENCY)	-0.00043 PER °C	-0.00043 PER °C
RADIATION (10 YEARS)		
SILICON		
CONVENTIONAL	0.75	0.75
THIN	0.85	0.85
GaAs	0.9	0.9

SOLAR CELL SELECTED CHARACTERISTICS

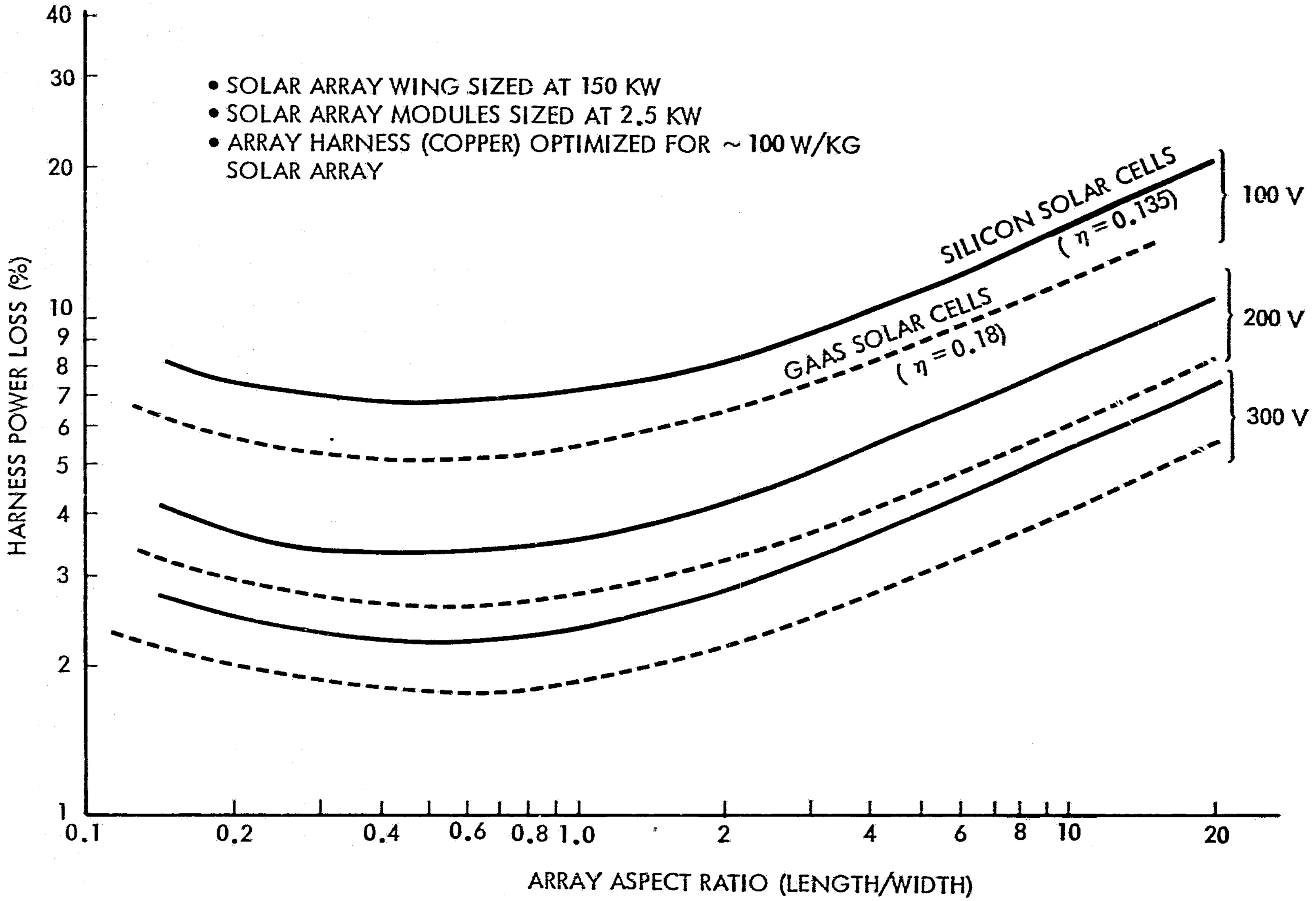
MATERIAL	CHARACTERISTICS	SIZE (CM)	THICKNESS (μM)	EFFICIENCY (%)	COVER	STACK WEIGHT (KG/M^2)	RELATIVE COST
SILICON	LARGE AREA	5 X 5	200	15	RTV 655	0.8	4
SILICON	IMPROVED TERRESTRIAL	7.6 DIA	375	14	RTV 655	1.5	1*
GaAs	LIQUID PHASE EPITAXIAL METHOD	2 X 4	150	18	RTV 655	1.2	15
GaAs	"INVERTED" GaAs/SAPPHIRE CHEMICAL VAPOR DEPOSITION METHOD METHOD	11 X 100	25	18	Al_2O_3	0.3	1

*ASSUMED CELL COST IS $8/W

SOLAR ARRAY HARNESS WEIGHT VERSUS ASPECT RATIO
(VOLTAGE SELECTION)



SOLAR ARRAY HARNESS POWER LOSS VERSUS ASPECT RATIO

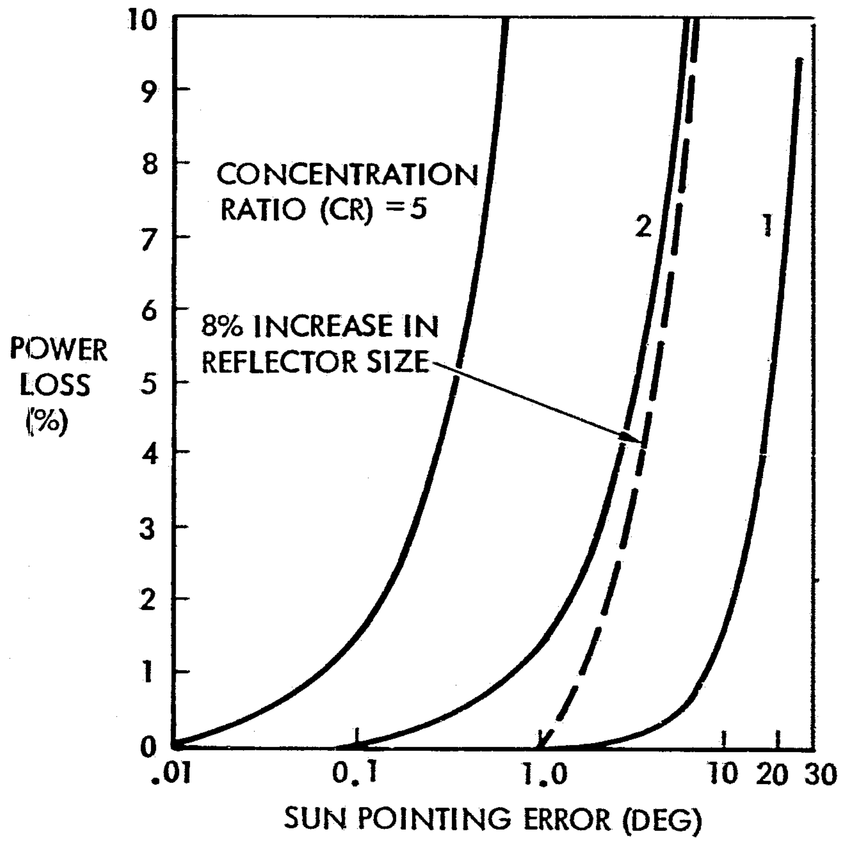


CONCENTRATION RATIO IMPACT ON SOLAR ARRAY ORIENTATION REQUIREMENTS

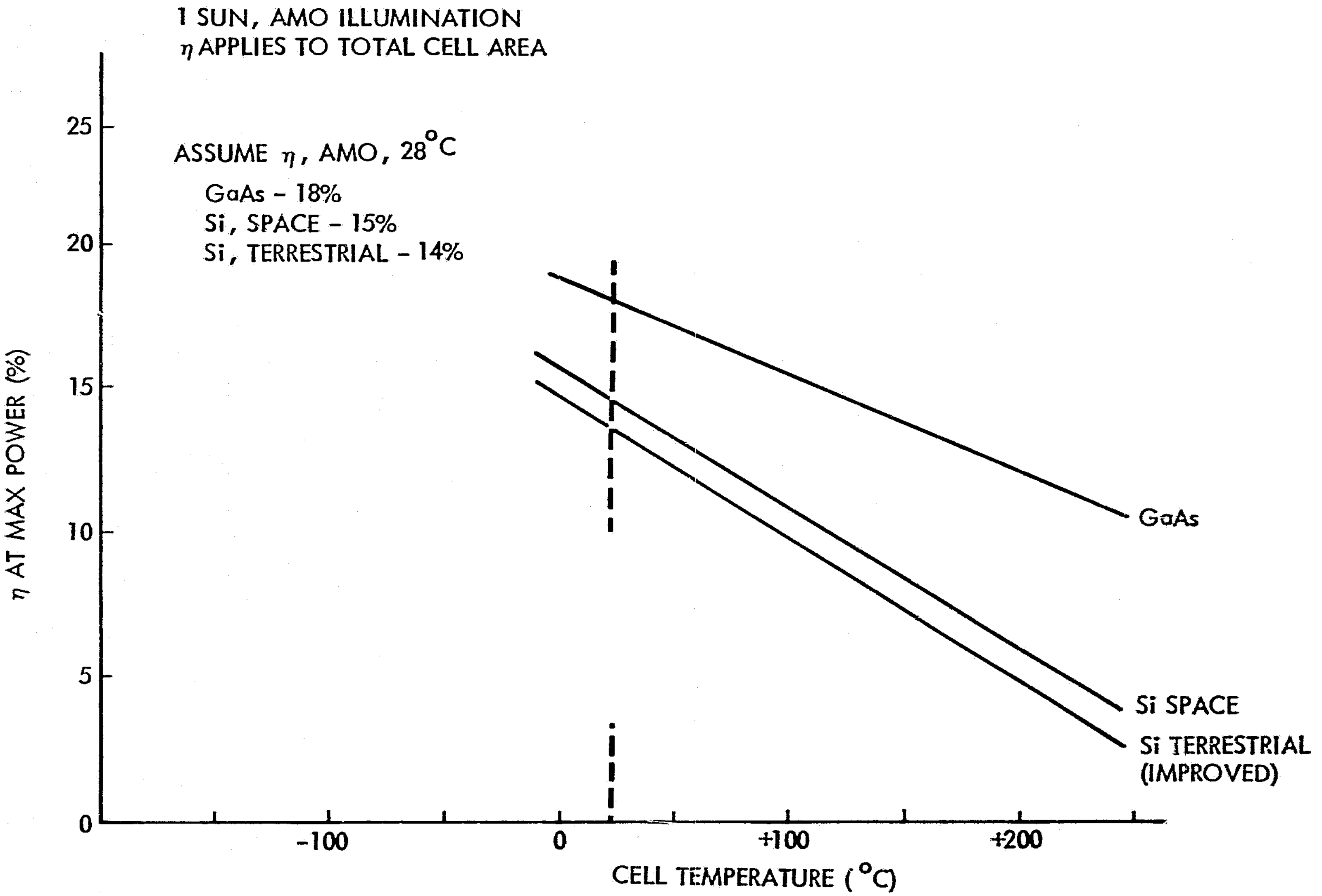
CR	POINTING ERROR (DEG)	POWER LOSS (%)
1	4.0	0.2
2	1.0 (MIN REFLECTOR)	1.6
2	1.0 (8% INCREASE IN REFLECTOR SIZE)	0
5	0.065	1.0
5	1.0	15.0
5	1.0 (43% INCREASE IN REFLECTOR SIZE)	0

- CR = 1, NO ATTITUDE OR FIGURE CONTROL PROBLEMS
- CR = 2, 8% INCREASE IN REFLECTOR SIZE RESULTS IN 100% COLLECTOR EFFICIENCY WITHOUT ACTIVE FIGURE CONTROL
- CR = 5, 43% INCREASE IN REFLECTOR SIZE RESULTS IN 100% COLLECTOR EFFICIENCY WITHOUT ACTIVE FIGURE CONTROL

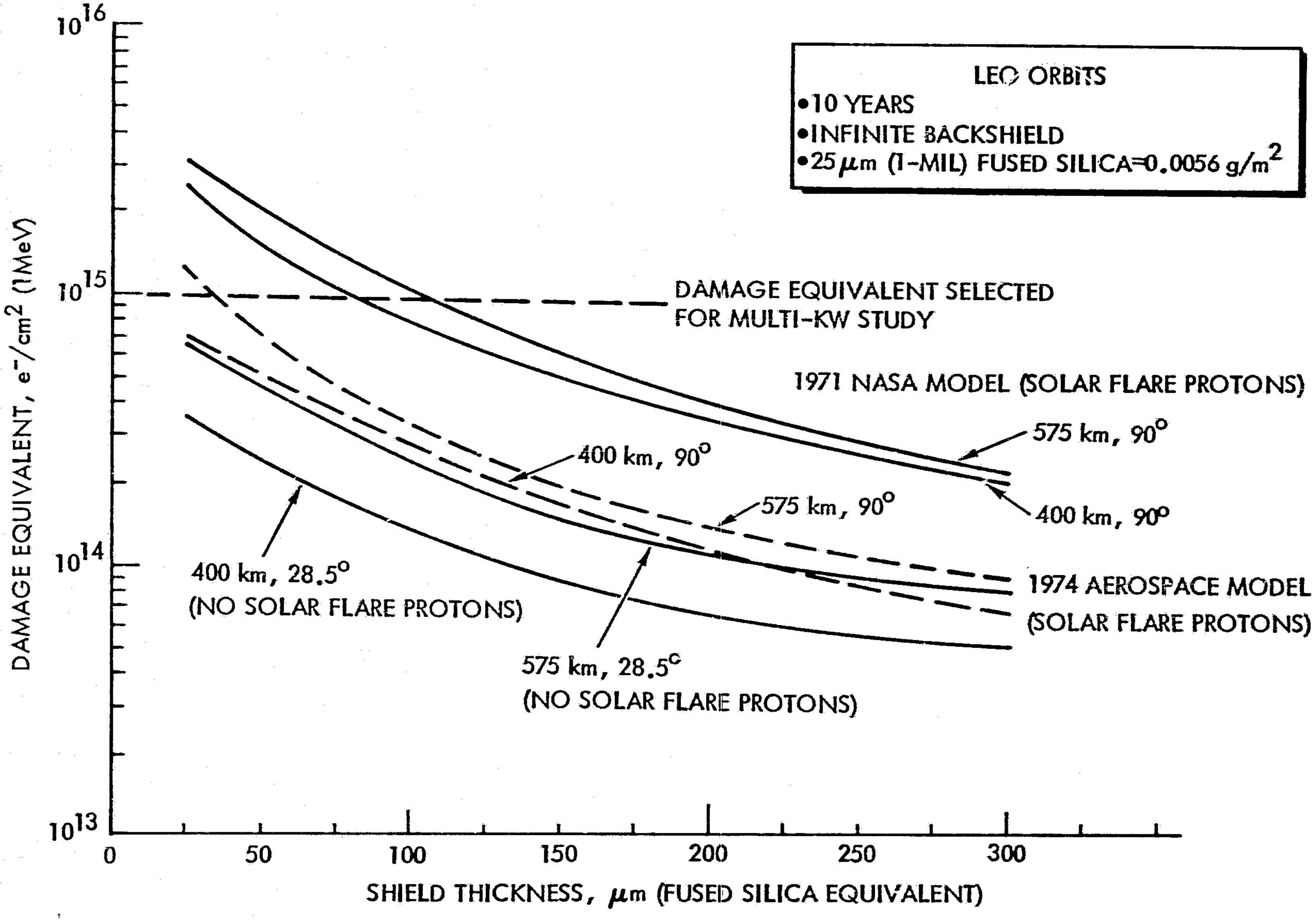
NOTE: "TROUGH" TYPE CONCENTRATOR ASSUMED



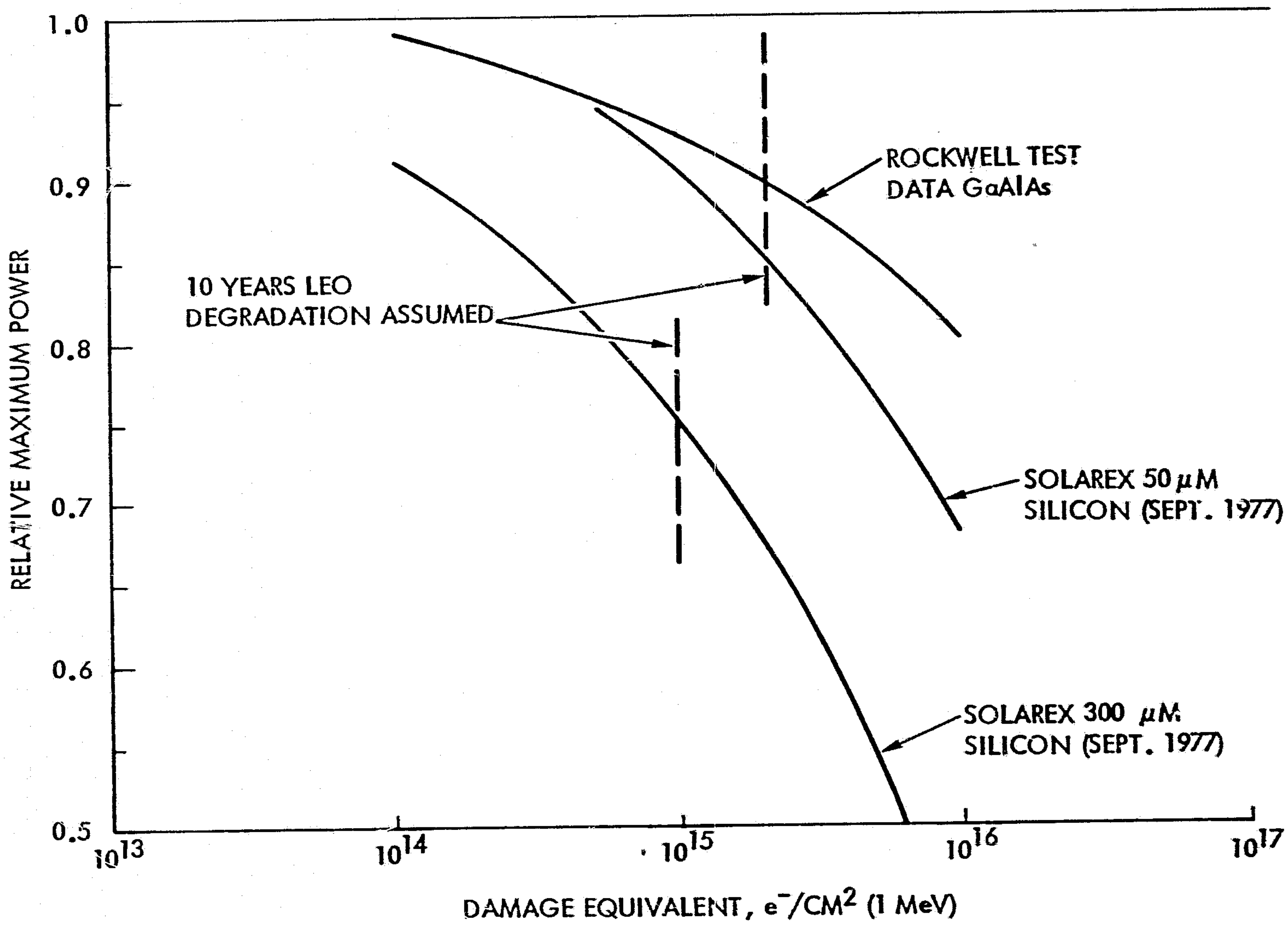
TEMPERATURE EFFECT ON CELL EFFICIENCY



SOLAR CELL DAMAGE EQUIVALENT 1-MeV ELECTRON FLUENCE



NORMALIZED MAXIMUM POWER VS 1 MeV ELECTRON FLUENCE



150-KW SOLAR ARRAY WING PLANAR DESIGN

SOLAR CELL ASSUMPTIONS					SOLAR CELL BLANKET ASSEMBLY COST ($/M²)*	DESIGN FACTORS						ARRAY BLANKET			ALLOWABLE STRUCTURE COST FOR $30/W GOAL $/M²
MATERIAL	EFF. %	SIZE (CM)	THICKNESS (μM)	COST $/M²		PF CELL GROUP	PF CELLS	FAB & ASSY	UV	HARNESS	TEMP**	AREA M²	COST $ X 10⁶	DOLLARS PER WATT	
SILICON	15	5 X 5	200	4,500	6,300	0.9	0.96	0.97	0.98	0.96	0.87	1,070	6.7	45	NEGATIVE
SILICON	14	7.6 (DIA)	375	900	1,900	0.9	0.85	0.97	0.98	0.96	0.87	1,300	2.5	17	1,500
GaAs (LPE)	18	2 X 4	150	21,000	24,000	0.9	0.94	0.97	0.98	0.96	0.94	840	22.6	151	NEGATIVE
GaAs (CVD)	18	11 X 100	25	1,400	2,000	0.9	0.98	0.97	0.98	0.96	0.94	840	1.7	11	3,300

LPE = LIQUID PHASE EPITAXIAL
CVD = CHEMICAL VAPOR DEPOSITION

*INCLUDES CELL COST
**ASSUMES 60°C FOR SILICON SOLAR ARRAY, 55°C FOR GaAs

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CONCENTRATOR TRADE STUDIES

OBJECTIVE

- TRADE LESS-EXPENSIVE REFLECTING STRUCTURE FOR SOLAR PANELS

CONCENTRATOR DRAWBACKS

- CELL OUTPUT DROPS DUE TO HIGHER TEMPERATURES
- REQUIRED POINTING ACCURACY INCREASES
- OPTICAL SYSTEM LOSES ENERGY
- SYSTEM HAS INCREASED COMPLEXITY

SPECIAL TOPICS

- STACK STRUCTURE; SPECTRAL SELECTIVITY

IDEAL CONCENTRATOR PERFORMANCE

- "REAL" SOLAR CELLS
- IDEAL OPTICS AND RADIATOR

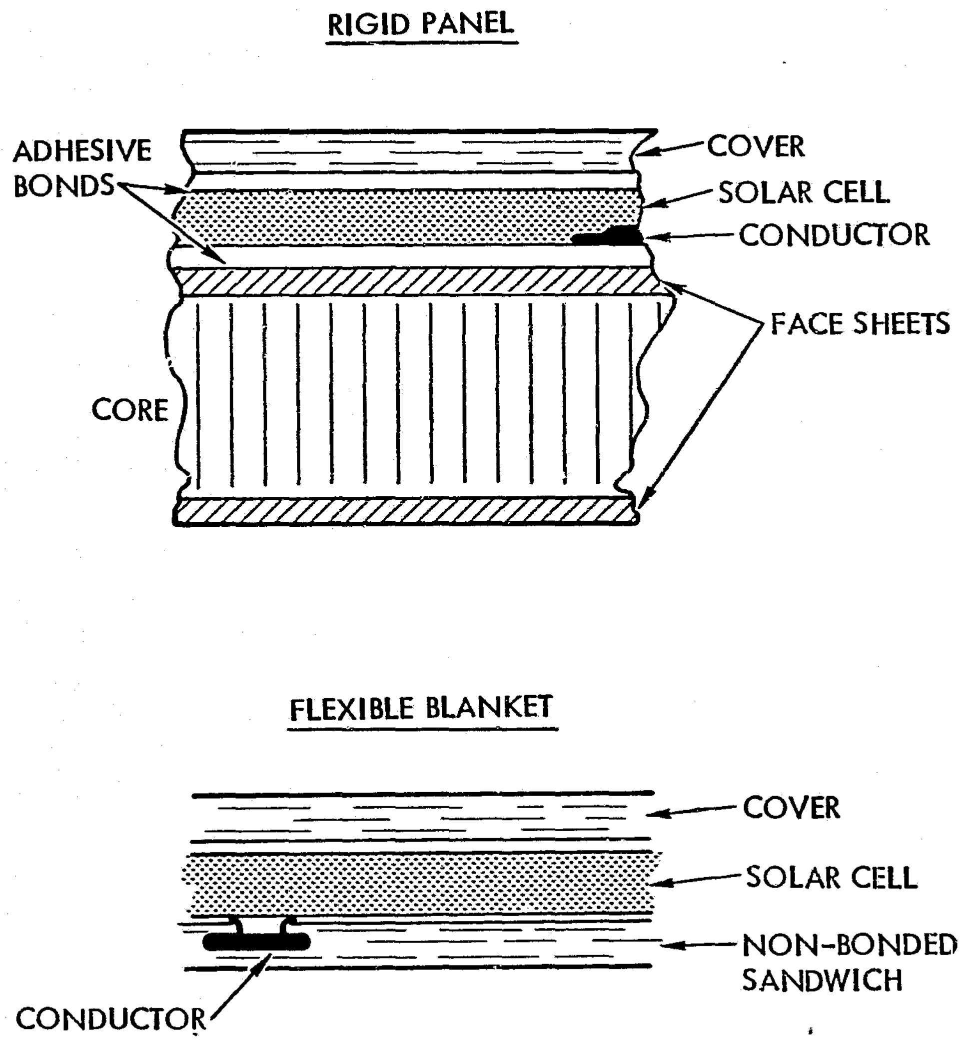
PERFORMANCE OF CONCENTRATOR FAMILIES

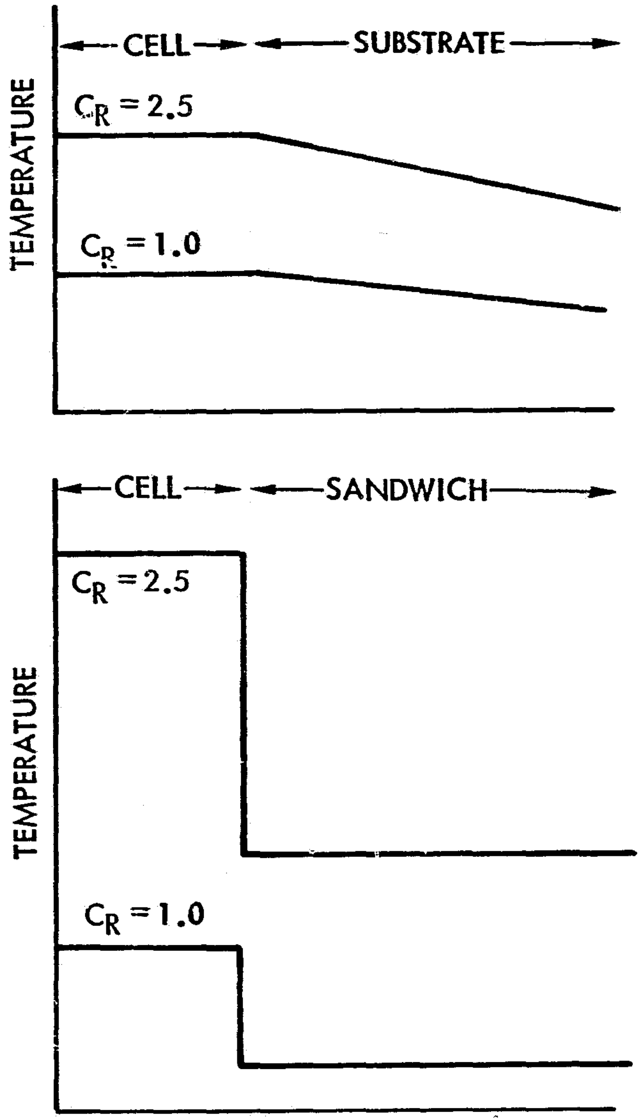
- "W" TROUGH
- SAWTOOTH TROUGH
- HEXAGONAL CONE
- PARABOLIC DISH
- CASSEGRAIN
- SLAT

COST TRENDS

CONCLUSIONS

INFLUENCE OF STACK STRUCTURE ON CELL TEMPERATURE

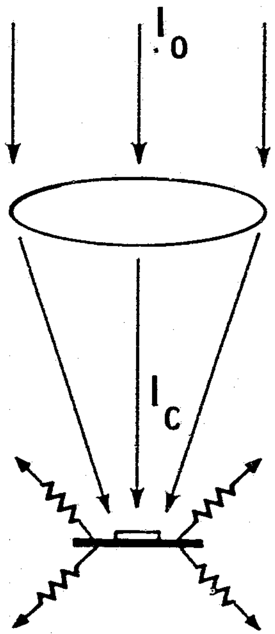




USE OF SPECTRAL SELECTIVITY IN CONCENTRATORS

- SPECTRALLY SELECTIVE REFLECTIVE COATINGS
  - ON FRONT SURFACE OF PRIMARY REFLECTOR
  - ON FRONT SURFACE OF CELL
  - ON BACK SURFACE OF CELL
- MULTIPLE CELLS WITH DIFFERENT SPECTRAL RESPONSE
  - CASCADED CELLS
  - BEAM SPLITTING

IDEAL CONCENTRATOR ANALYSIS



ASSUMPTIONS

CELL, RADIATOR SURFACE PROPERTIES: $\alpha = \epsilon = 1.0$

RADIATOR VIEW FACTOR TO SPACE: F = 2 (TWO SIDES)

CONCENTRATOR OPTICAL EFFICIENCY: $\eta_{OPT} = 1.0$

RADIATOR EFFICIENCY: $\eta_{RAD} = 1.0$

CELL PACKING FACTOR: $f = 0.92 - 0.015 \ln(CR)$

CR = GEOMETRIC CONCENTRATION RATIO --
APERTURE AREA ÷ GROSS CELL AREA

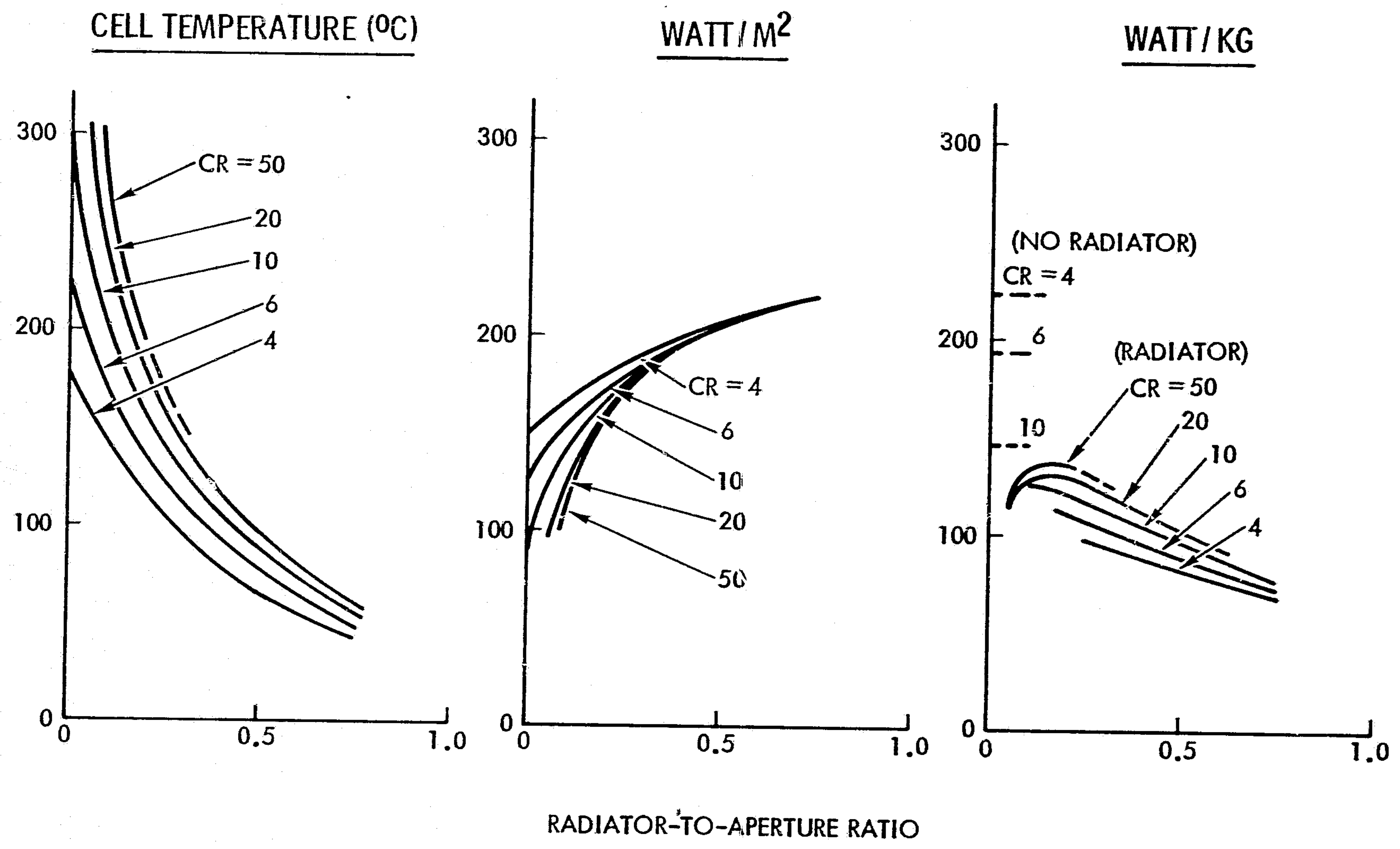
CELL CONVERSION EFFICIENCY

(Si) $\eta_C = 0.167 - 0.0006\,T\,(C) + 0.0052 \ln(CR)$
(GaAs) $\eta_C = 0.187 - 0.00043\,T\,(C) + 0.0083 \ln(CR)$

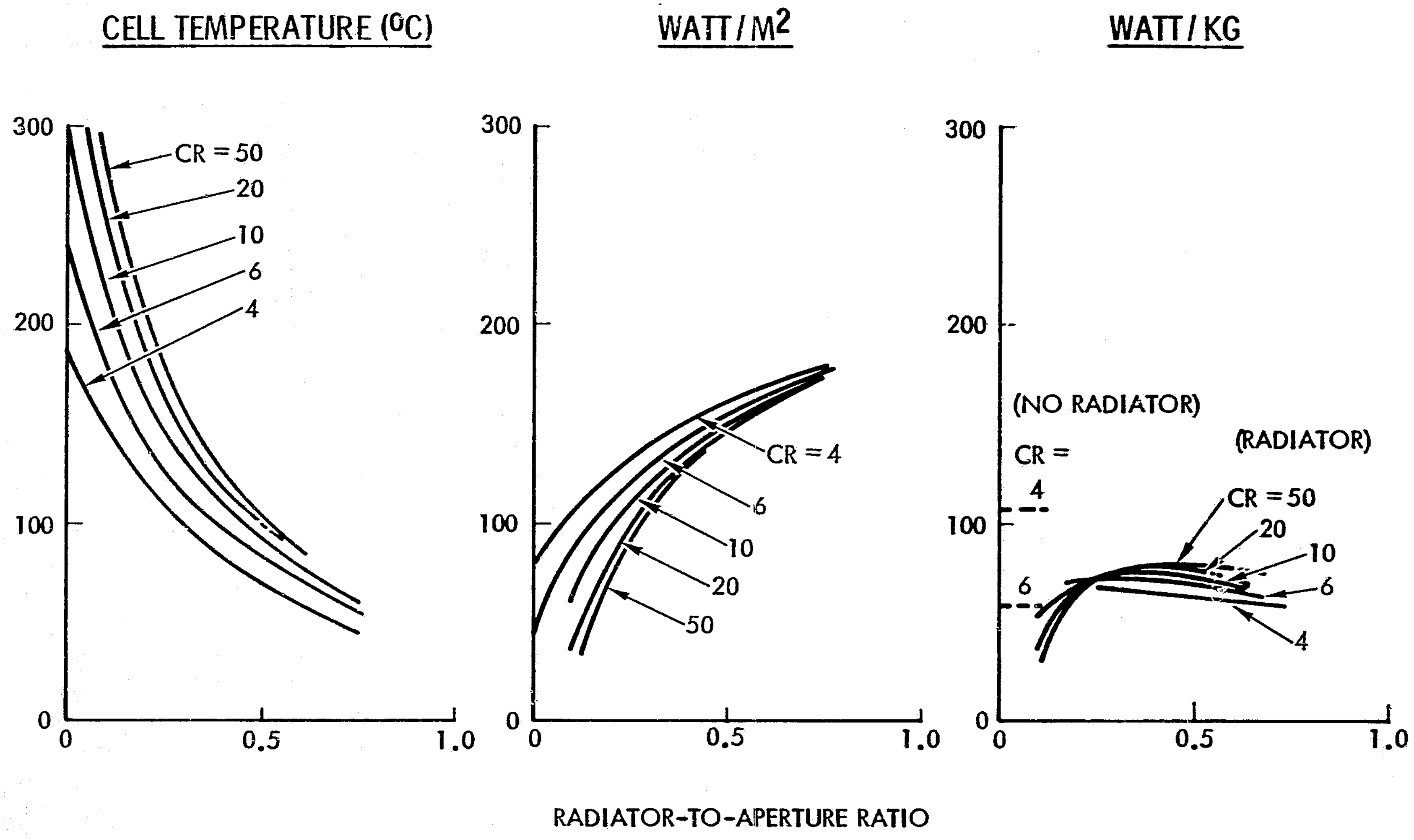
SPECIFIC MASSES (KG/M^2)

Si CELLS: 0.4	GaAs CELLS: 0.25
STRUCTURE/OPTICS: 0.6	RADIATOR: 2.50

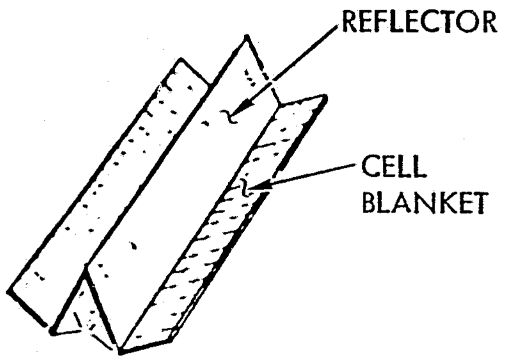
IDEAL CONCENTRATOR PERFORMANCE
(GALLIUM ARSENIDE CELLS)



IDEAL CONCENTRATOR PERFORMANCE
(SILICON CELLS)



"W" TROUGH PERFORMANCE
(C.R. = 1.4)



ASSUMPTIONS:

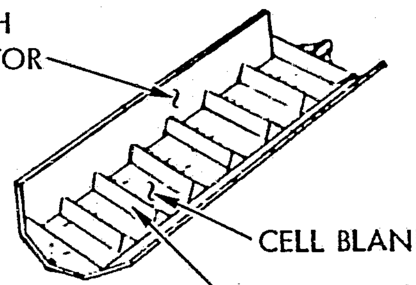
REFLECTIVITY 0.87
50% SINGLE REFLECTION
50% DIRECT (45° INCIDENCE)

TOP AND BOTTOM VIEW FACTORS

$$\left(\frac{1 + .87}{2}\right) = 0.935$$

CELL MATERIAL	CELL TEMP. (C)	WATTS/SQ M	WATTS/KG
GaAs	59	188	228
SILICON	63	150	164

SAWTOOTH/TROUGH PERFORMANCE
(C.R. = 4.0)



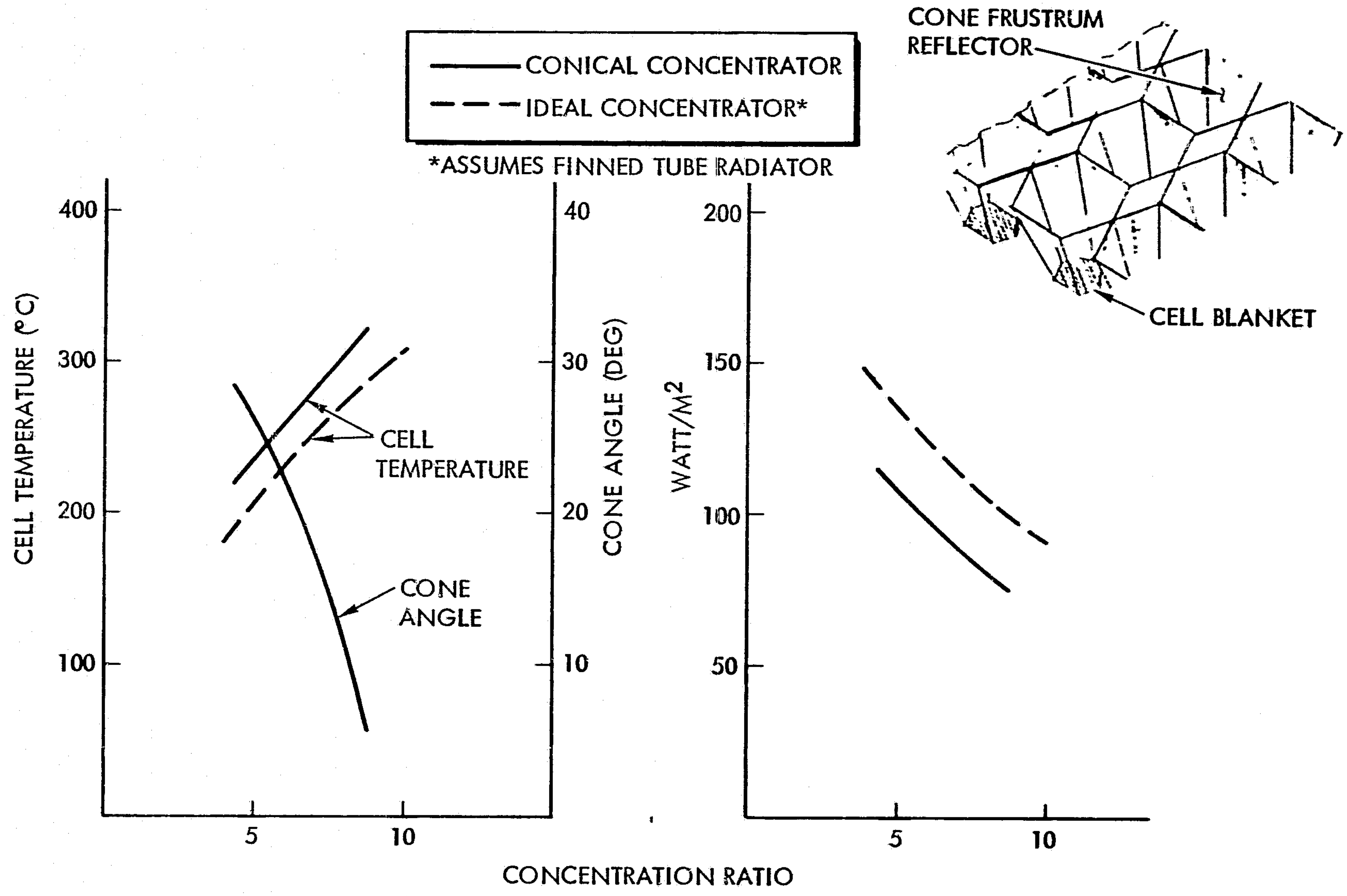
ASSUMPTIONS:

REFLECTIVITY 0.87
50% DOUBLE REFLECTIONS
25% SINGLE REFLECTIONS
25% DIRECT REFLECTIONS

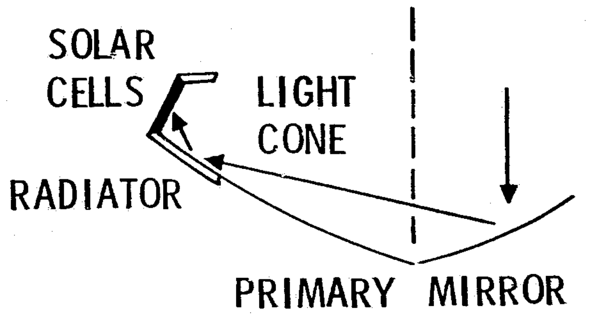
TOPSIDE VIEW FACTOR 0.85

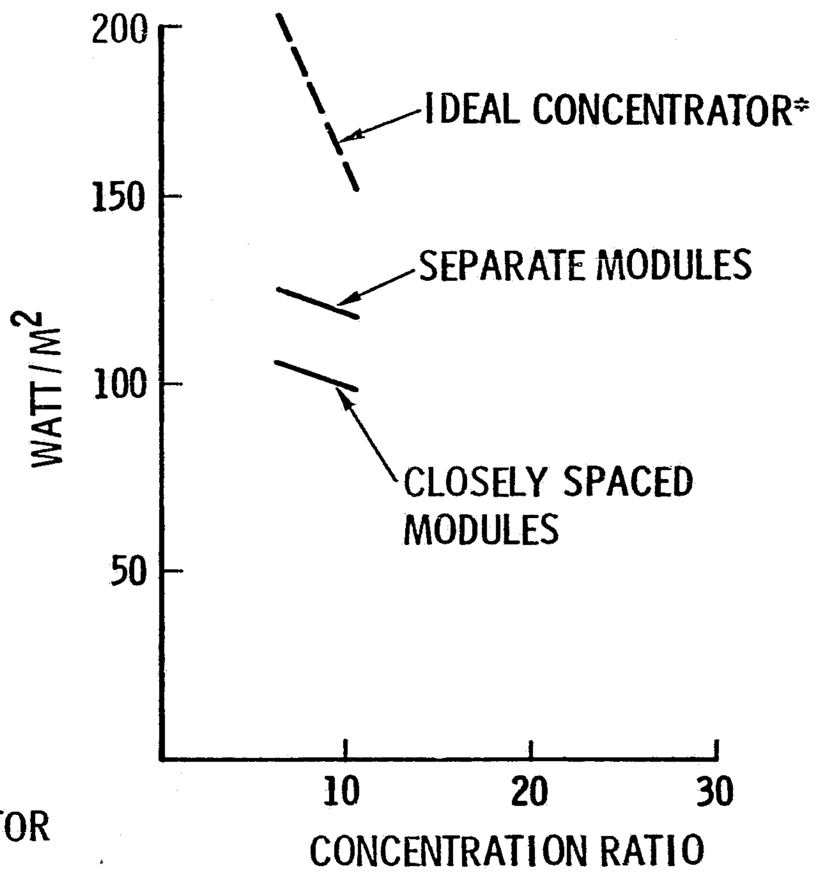
CELL MATERIAL	CELL TEMP. (C)	WATTS/SQ M	WATTS/KG
GaAs	151	137	166
SILICON	159	81	88

TRUNCATED HEXAGONAL CONE
(GALLIUM ARSENIDE)



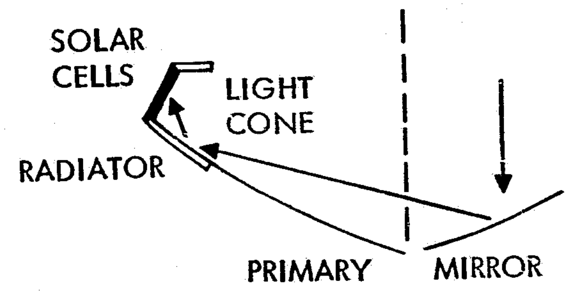
PARABOLIC CONCENTRATOR PERFORMANCE
(GALLIUM ARSENIDE)

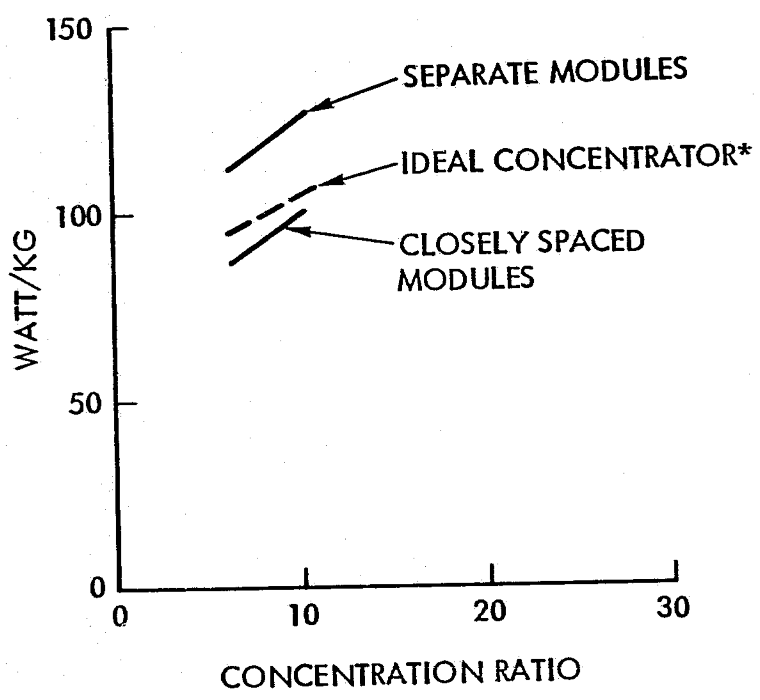


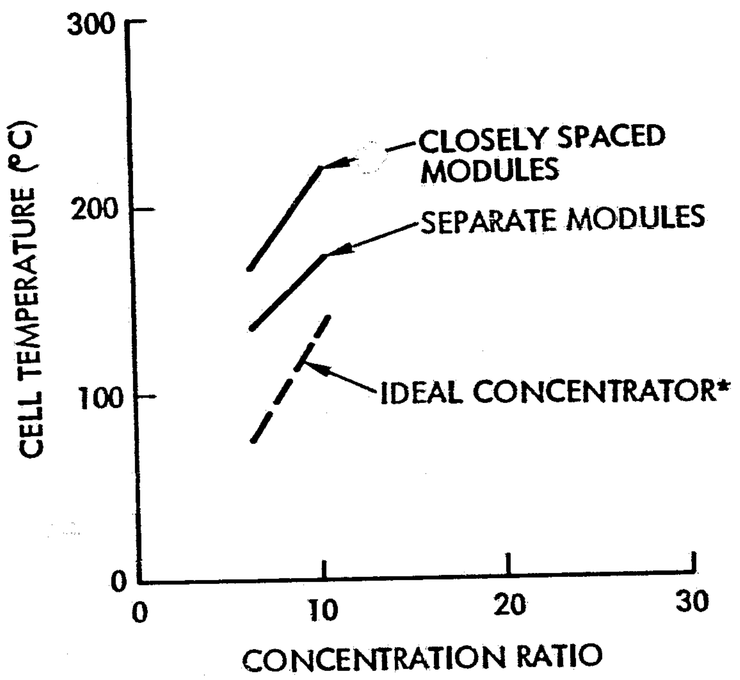


*ASSUMES FINNED TUBE RADIATOR

PARABOLIC CONCENTRATOR PERFORMANCE
(GALLIUM ARSENIDE)

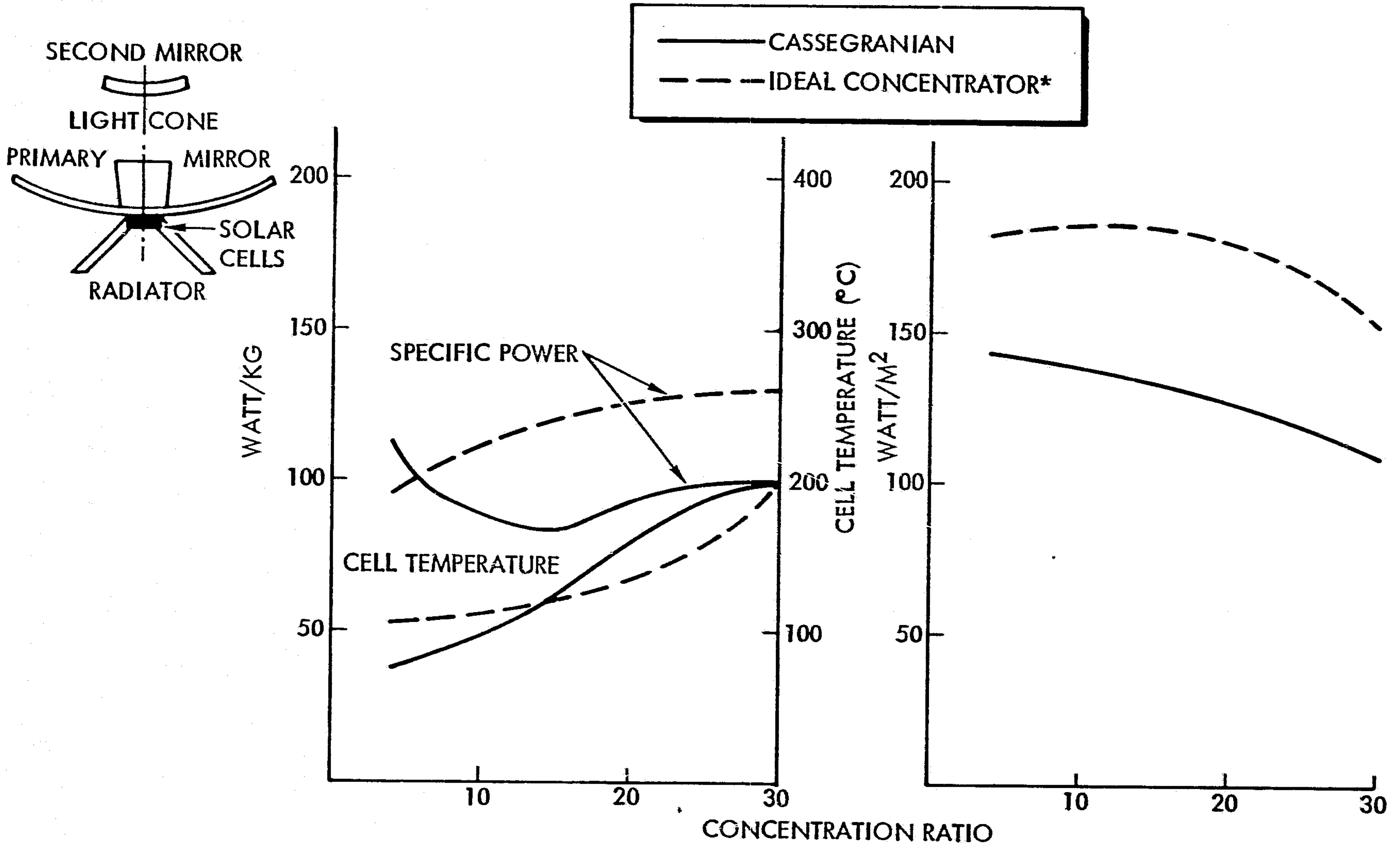






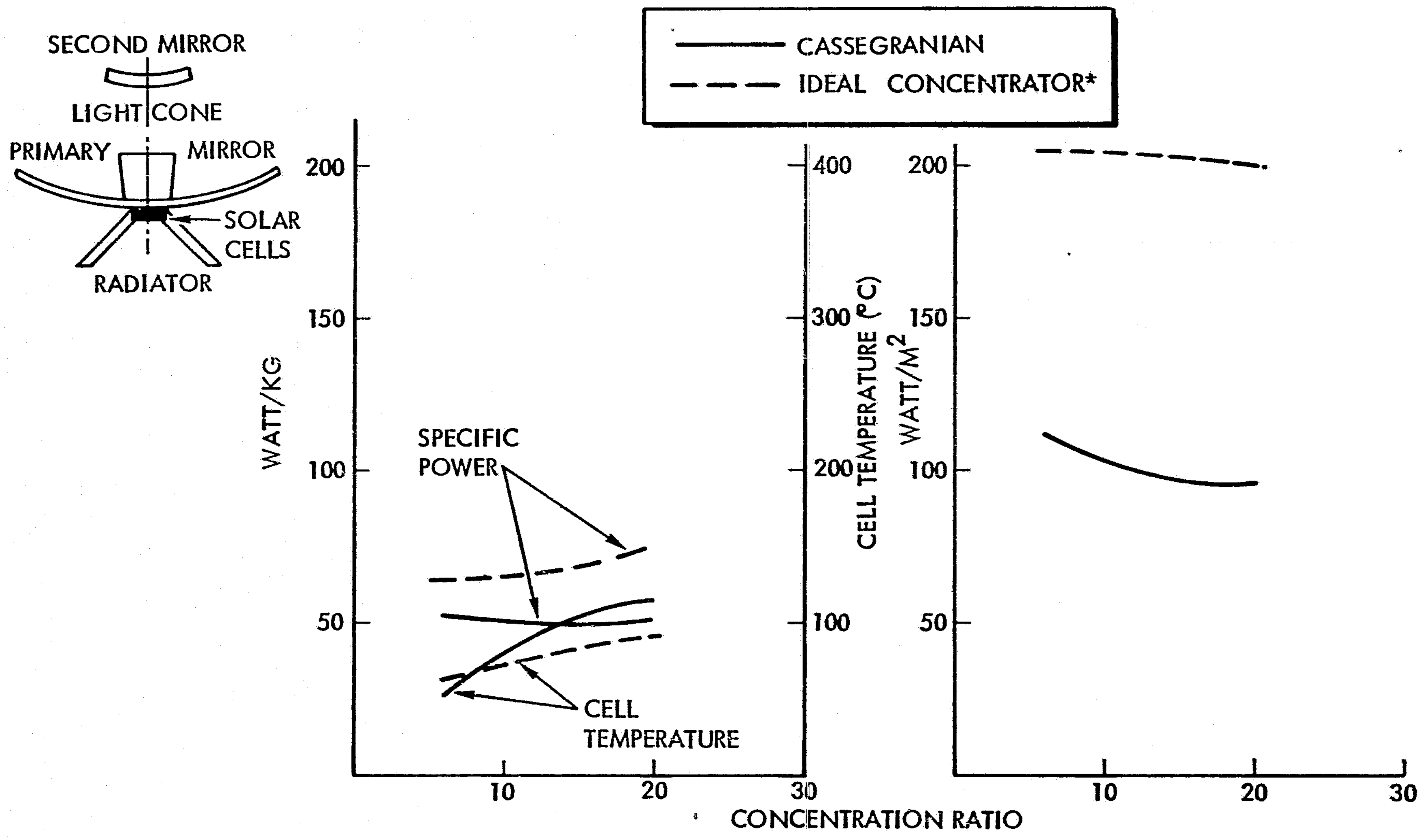
*ASSUMES FINNED TUBE RADIATOR

CASSEGRAIN CONCENTRATOR PERFORMANCE
(GALLIUM ARSENIDE)



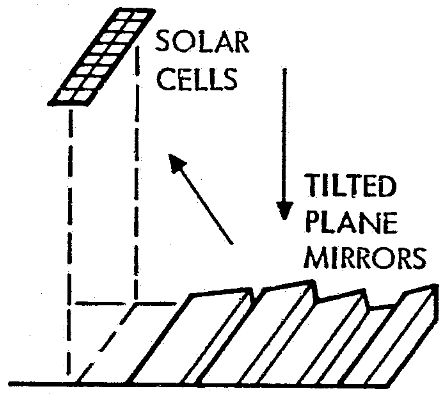
*ASSUMES FINNED TUBE RADIATOR

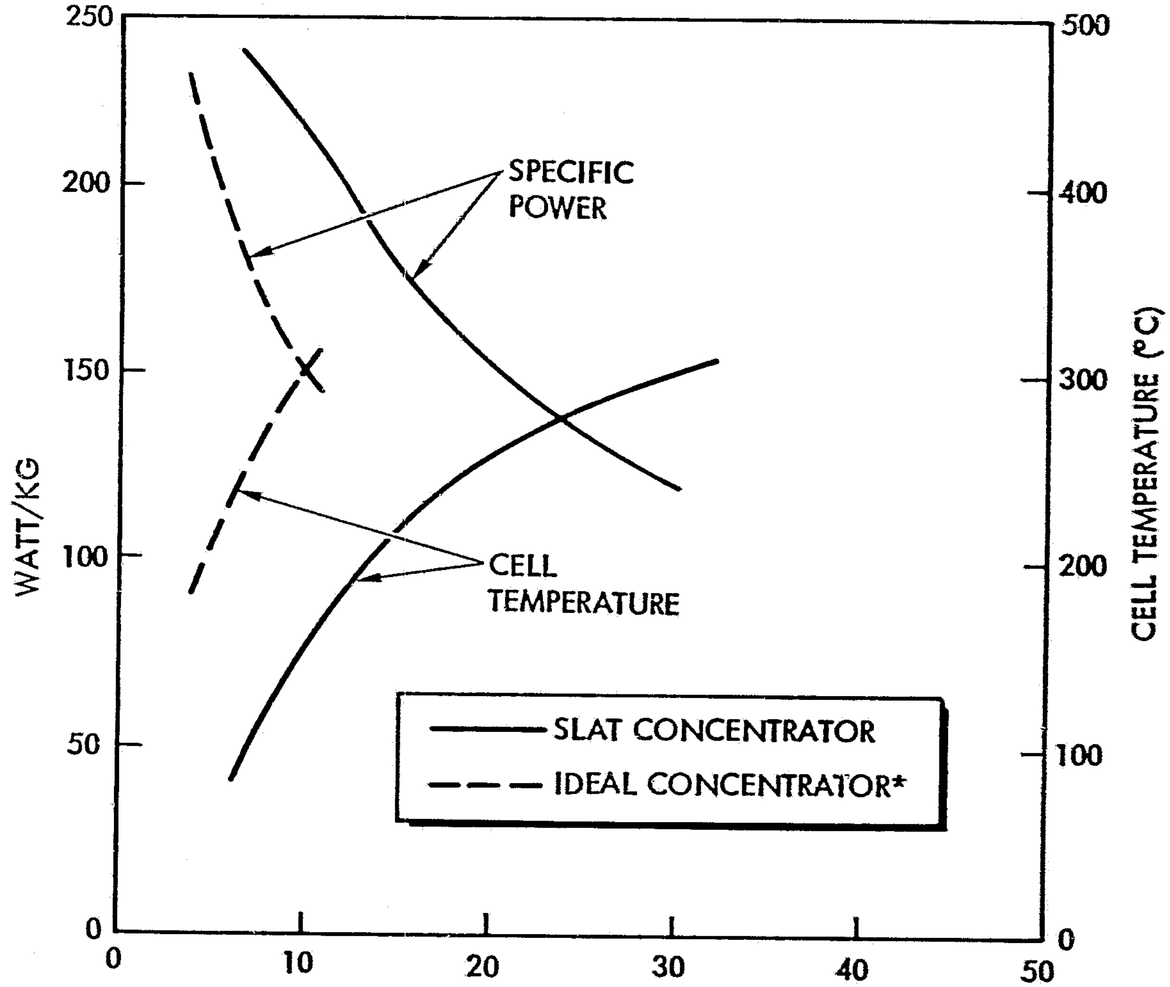
CASSEGRAIN CONCENTRATOR PERFORMANCE
(SILICON)



*ASSUMES FINNED TUBE RADIATOR

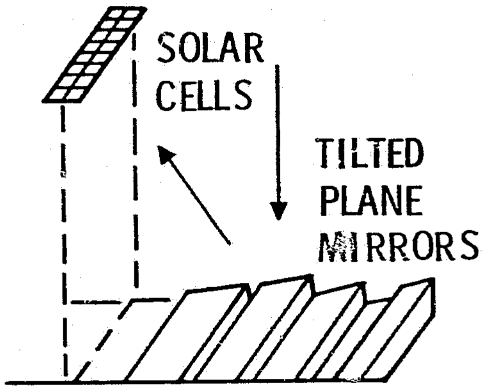
SLAT CONCENTRATOR PERFORMANCE
(GALLIUM ARSENIDE)

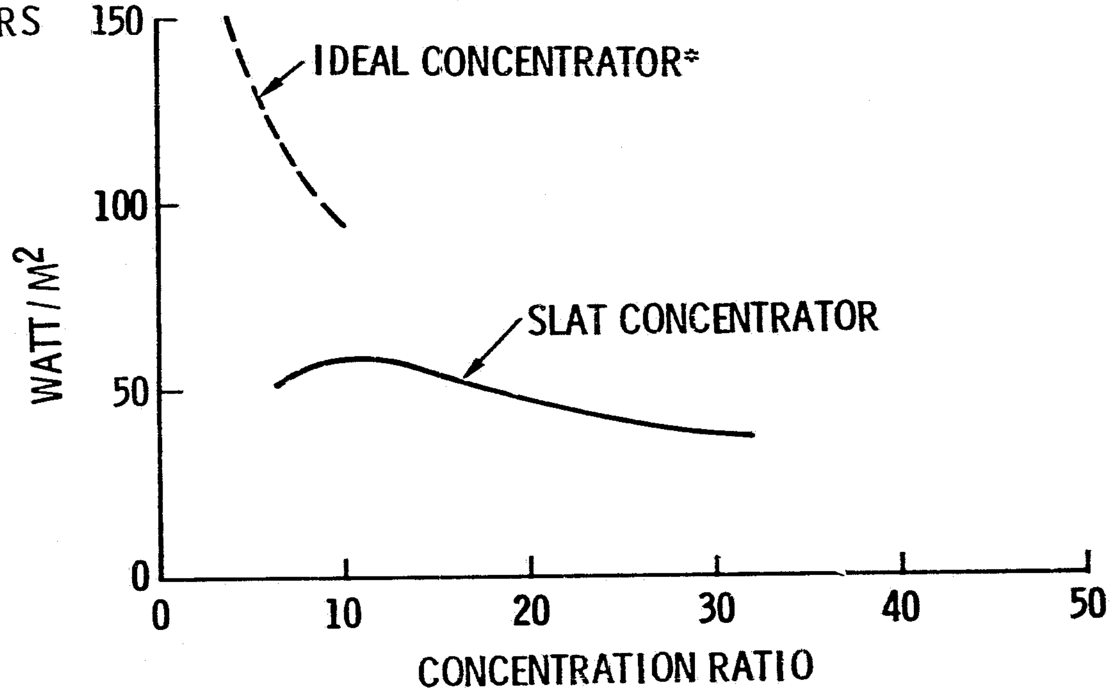




*ASSUMES FINNED TUBE RADIATOR

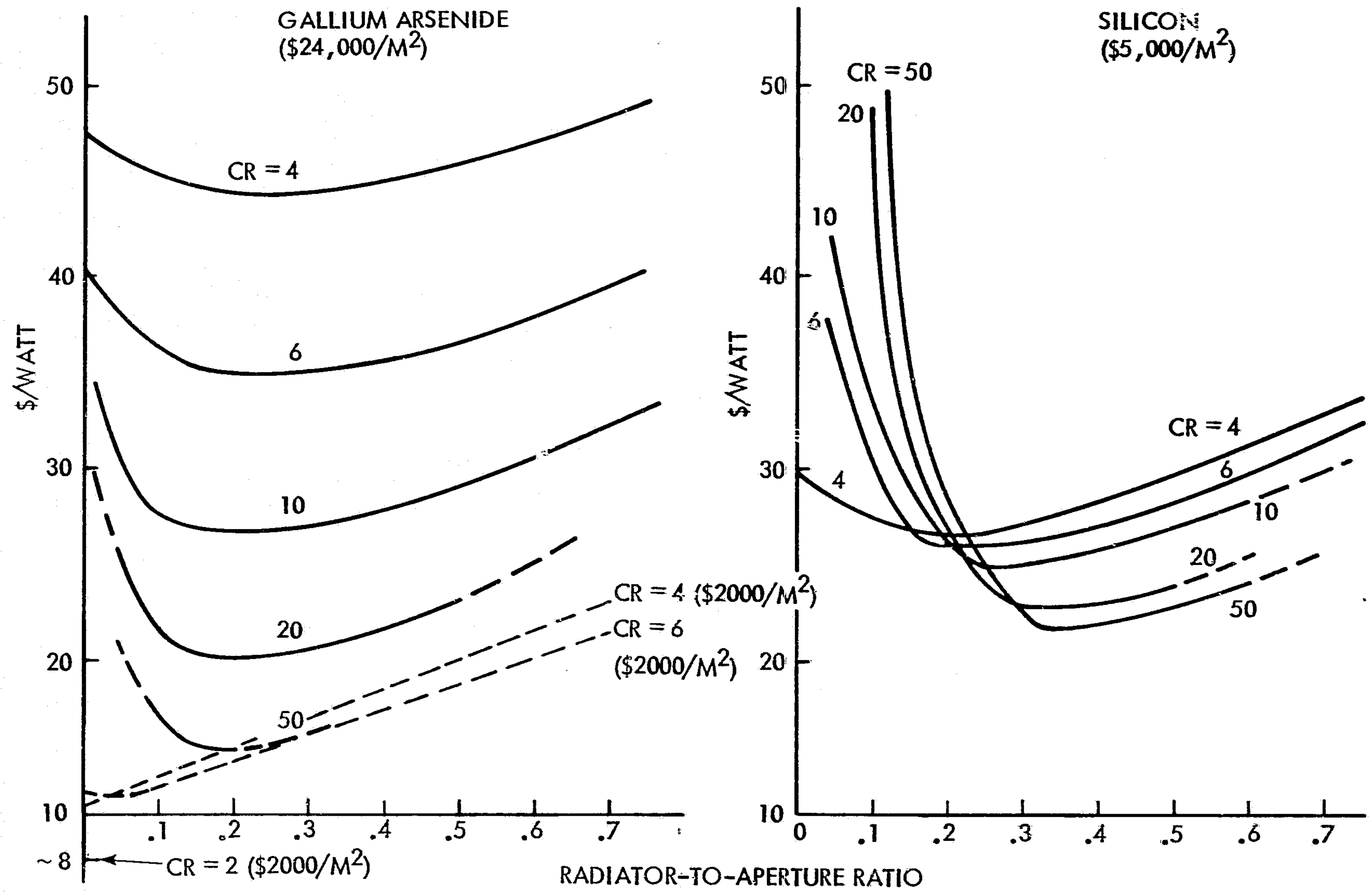
SLAT CONCENTRATOR PERFORMANCE
(GALLIUM ARSENIDE)





*ASSUMES FINNED TUBE RADIATOR

IDEAL CONCENTRATOR COST TRENDS
(FINNED TUBE RADIATOR COST = $5,000/M²; OPTICS/STRUCTURE COST $1000/M²)



CONCENTRATOR STUDY CONCLUSIONS

- SOLAR PANELS FOR CONCENTRATORS MUST HAVE GOOD THERMAL BONDING THROUGHOUT STACK

- CONCENTRATORS MUST USE ADDITIONAL RADIATING SURFACES ABOUT $CR \approx 6$

- PERFORMANCE ON A WATT/M^2 OR WATT/KG BASIS IS NOT IMPROVED SIGNIFICANTLY BY LARGE CR VALUES

- PERFORMANCE ALONE DOES NOT PERMIT SELECTION OF A SINGLE CONCENTRATOR CONCEPT

- ON IDEAL BASIS, BOTH GaAs & SILICON APPEAR CAPABLE OF GIVING ~ \$30/WATT AT MODERATE CR

BRIEFING OUTLINE

OVERVIEW

- OBJECTIVES
- APPROACH
- GROUNDRULES/REQUIREMENTS

  – S.J. NALBANDIAN

DESIGN CONCEPTS

- SOLAR ARRAY/CELL TECHNOLOGY
  – S.J. NALBANDIAN
- CONCENTRATOR CONCEPTS
  – E.P. FRENCH
- CONFIGURATION TRADES
  - DEPLOYMENT MODES
  - PLANAR
  - CONCENTRATOR

    –J.A. MENAGER

ON-ORBIT MAINTAINABILITY

- SHUTTLE CAPABILITY
- MAINTENANCE TRADES

  – S.J. NALBANDIAN

SUMMARY

- PRELIMINARY CONCLUSIONS
- PLANNED ACTIVITIES

  –S.J. NALBANDIAN

STRUCTURAL/MECHANICAL DESIGN STUDY FOR 300 TO 1000KW

- OBJECTIVE
  - $30.00/WATT RECURRING SYSTEM COST
- BACKGROUND
  - SEPS STATE OF THE ART EXAMINED TO UTILIZE PRESENT-DAY TECHNOLOGY WITH NEXT-GENERATION IMPROVEMENTS REQUIRED TO MEET EXTREMELY LIGHTWEIGHT/LOW-COST AUTONOMOUSLY DEPLOYED STRUCTURES
- APPROACH
  - COMPARATIVE TRADE EVALUATION OF CR MIRRORS MADE TO DETERMINE IMPACTS INVOLVED (E.G., WEIGHT, COSTS, DEPLOYMENT, STOWAGE, & PERFORMANCE CHARACTERISTICS)
- SUMMARY
  - STRUCTURAL/MECHANICAL SYSTEMS IN 100- TO 300-KW MODULES APPEAR TO BE IN AN OPTIMUM SIZE RANGE FOR A FULLY AUTONOMOUSLY DEPLOYED/HIGH-DENSITY STOWED SYSTEM, THEREBY REDUCING STS ON-ORBIT OPERATIONAL COSTS & LINEAR PAYLOAD BAY LENGTH

CONCENTRATOR DEPLOYMENT EVALUATION

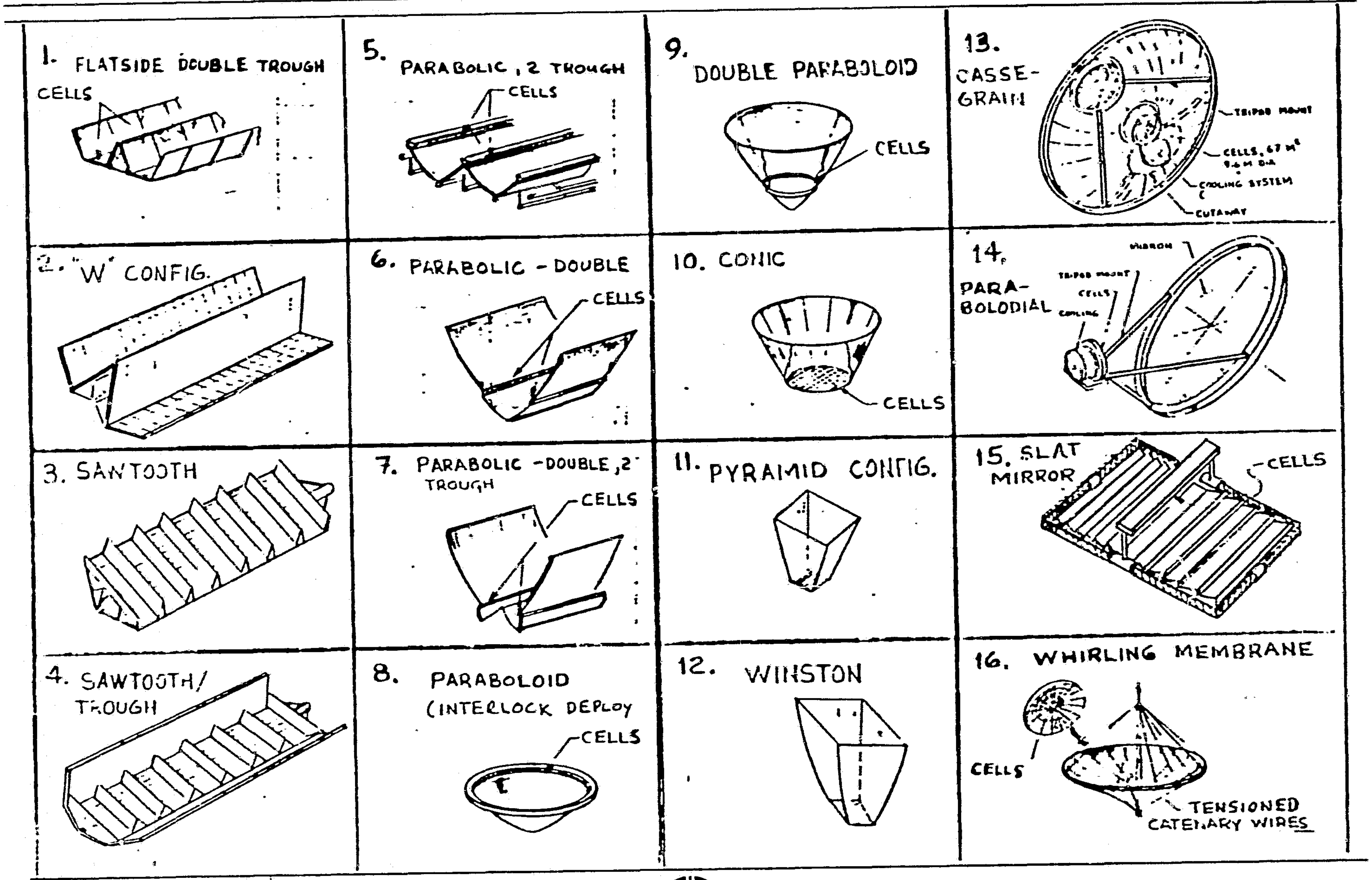
CANDIDATES (CR 1 THROUGH 10)

1. PLANAR
2. TROUGH/SAWTOOTH
3. "W"
4. PARABOLIC TROUGH
5. PARABOLOIDAL
6. TRUNCATED HEX
7. FRESNEL MIRROR
8. FRESNEL MIRROR CASSEGRAIN
9. CASSEGRAIN

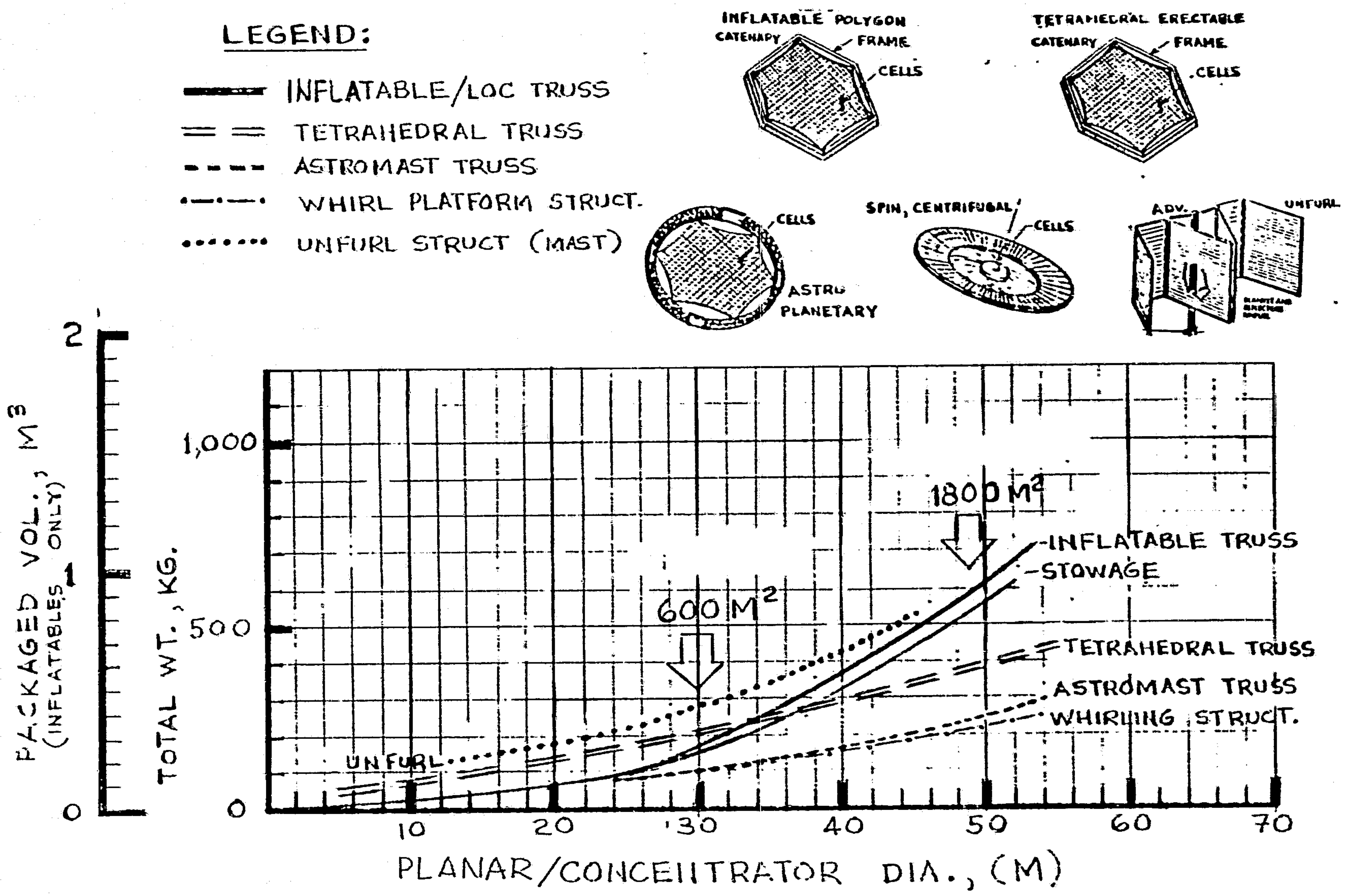
DESIGN TRADES

- ROLLUP
- FOLDUP
- AUTONOMY
- SIZE LIMITATIONS
- INFLATABLES
- SPRING LOADED
- STOWAGE FACTOR
- PACKAGING FACTOR (CELL-TO-MIRROR AREA)
- COMPLEXITY
- RELIABILITY
- WEIGHT
- CR OPTIMUM

CONCENTRATOR CANDIDATES



DEPLOYABLE VERSUS ERECTABLE STRUCTURES



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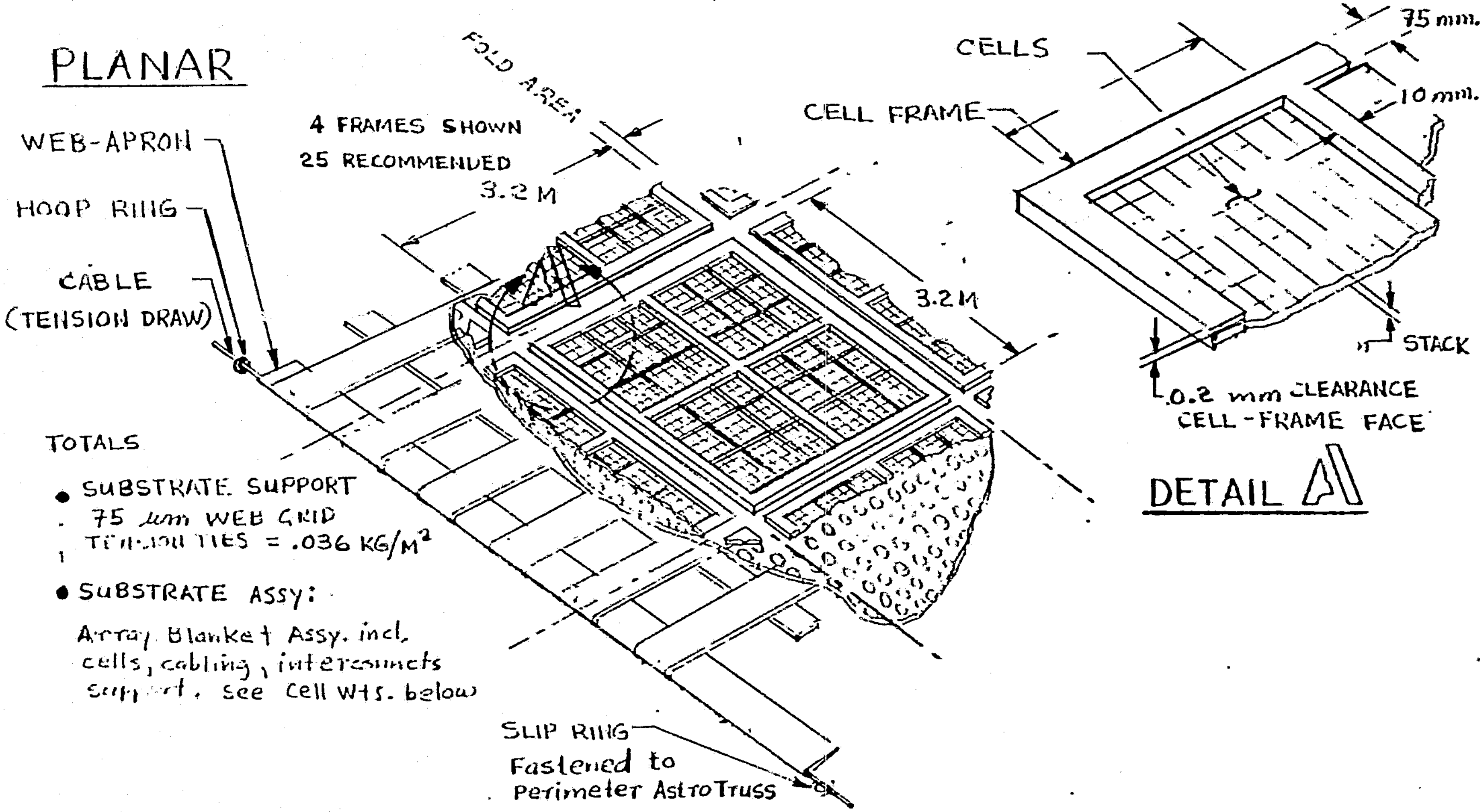
OF POOR QUALITY

ARRAY BLANKET ASSEMBLY
SHOWN IN PLANAR CONFIGURATION



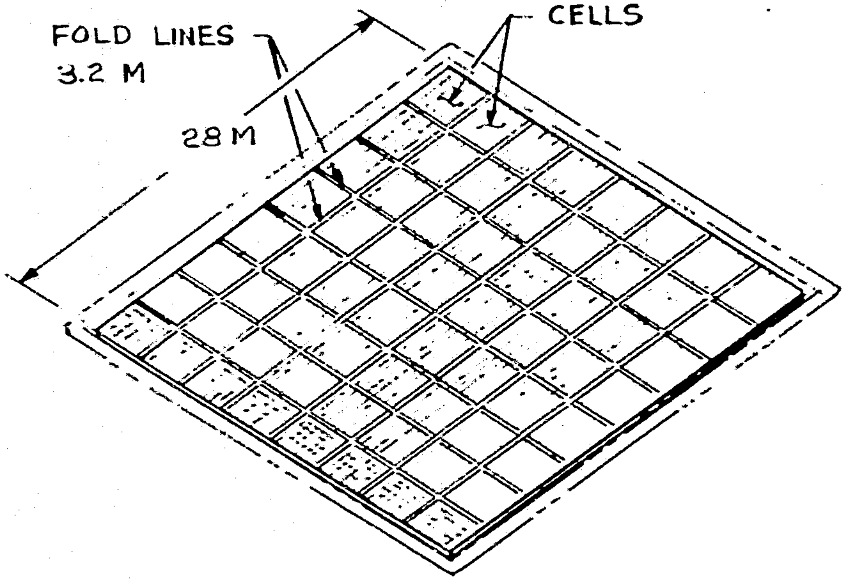
TOTALS

- SUBSTRATE SUPPORT
  75 μm WEB GRID
  TENSION TIES = .036 KG/M^2
- SUBSTRATE ASSY:

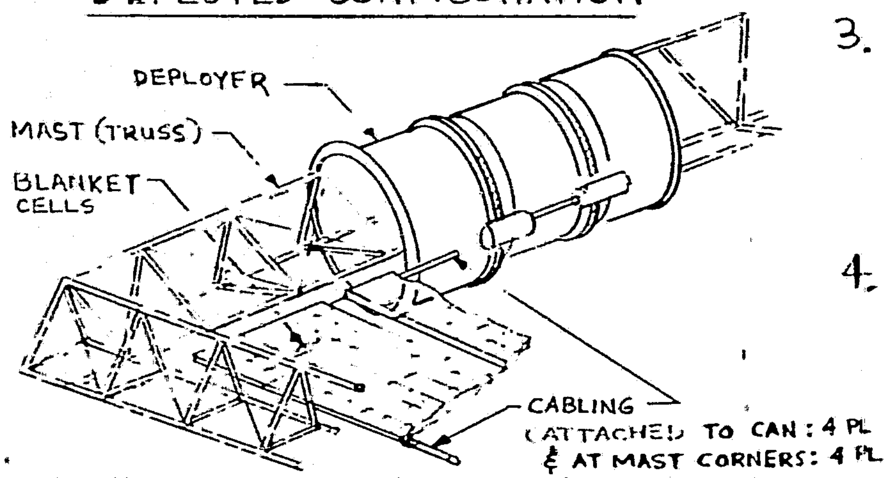
  Array Blanket Assy. incl. cells, cabling, interconnects support, see Cell Wts. below

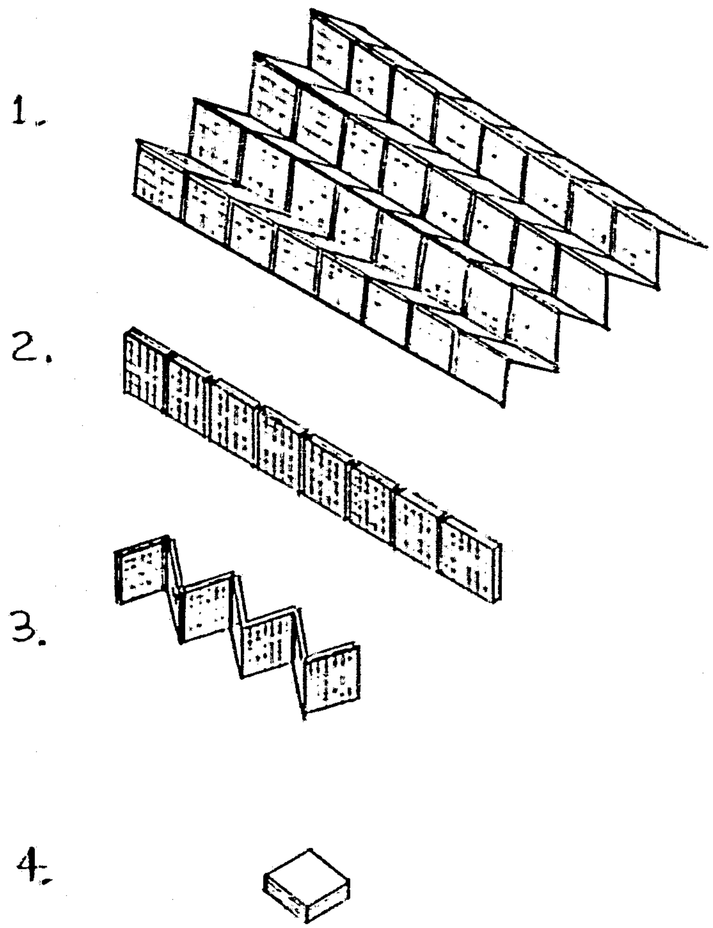
PLANAR BLANKET DESIGN EVALUATION

PLANAR



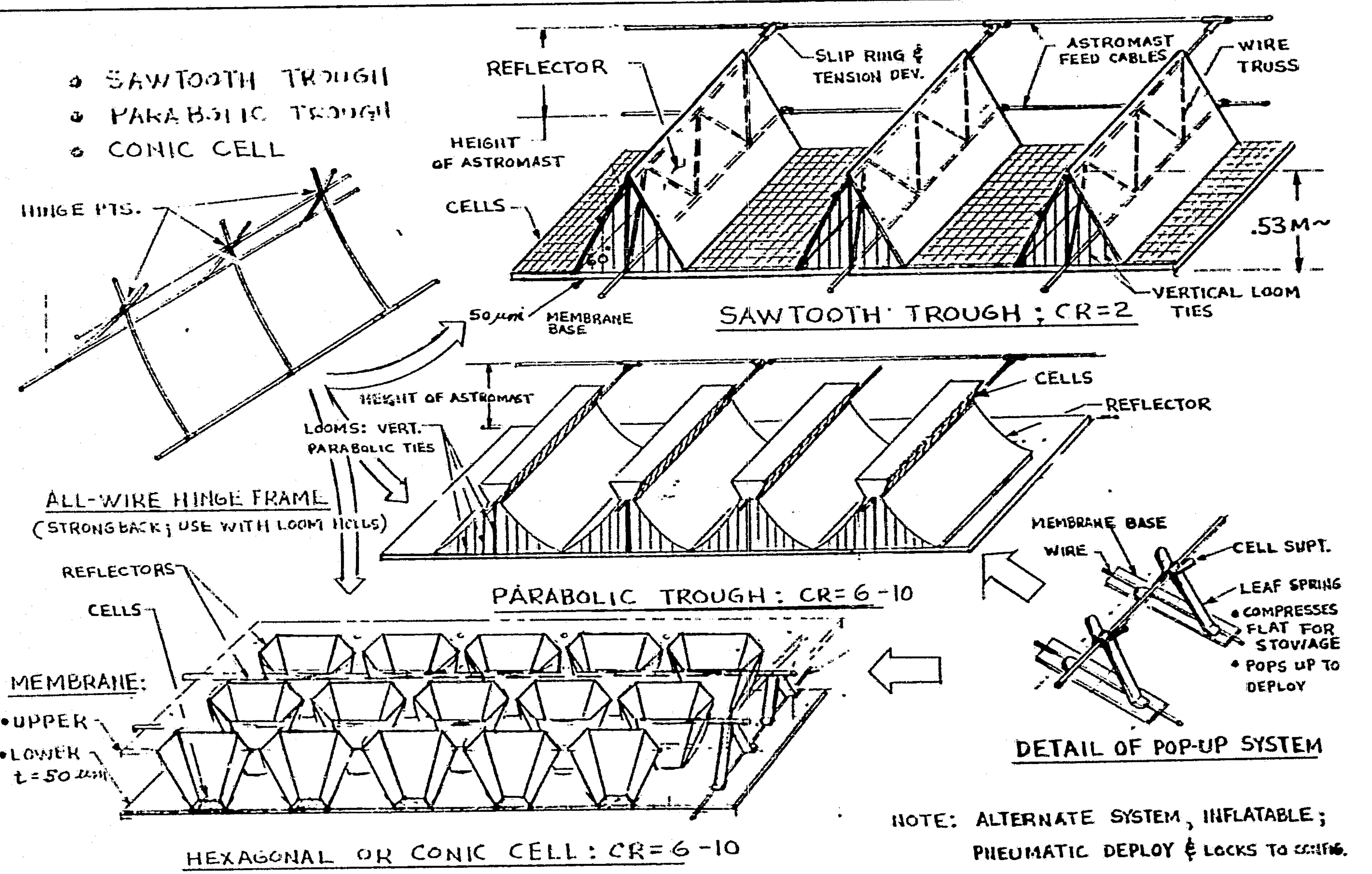
DEPLOYED CONFIGURATION





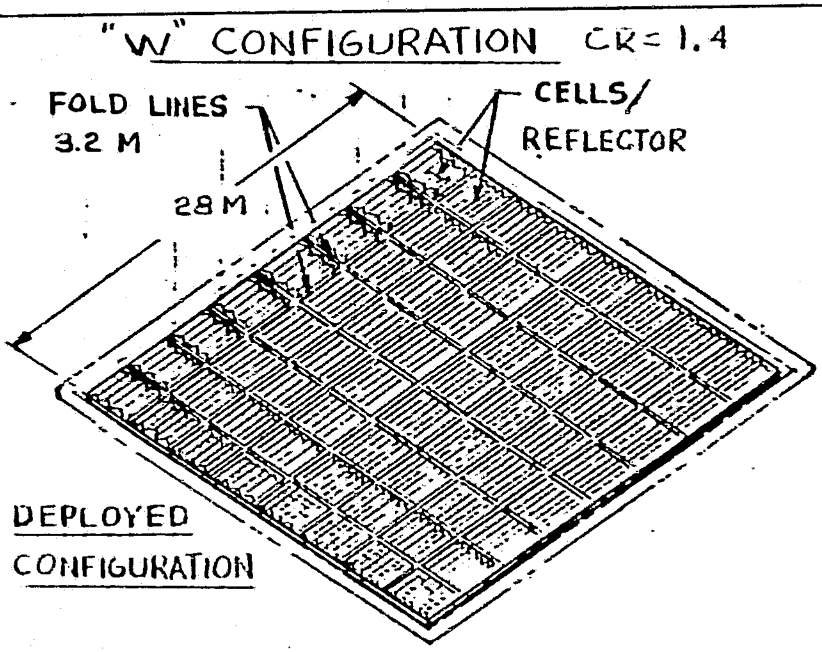
FOLDED SEQUENCE

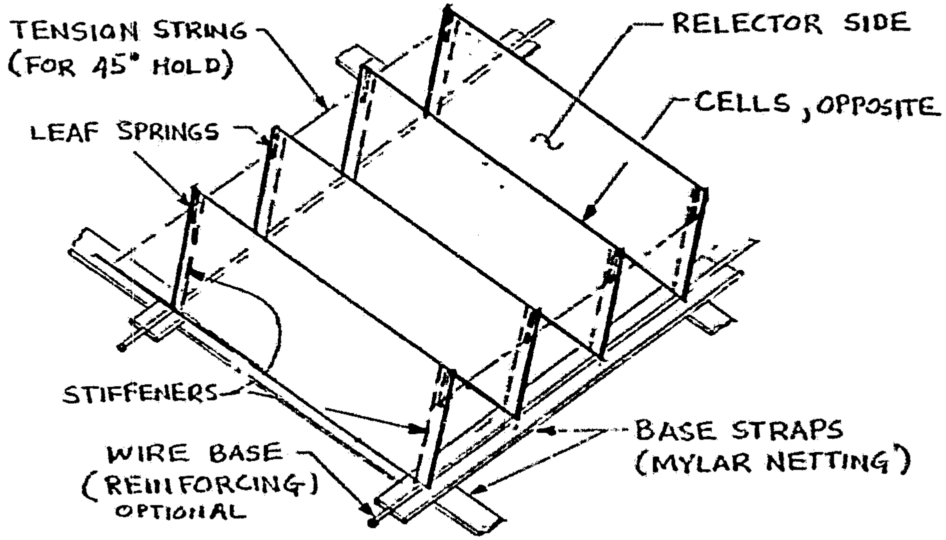
SOLAR CONCENTRATION DESIGN STUDIES (SMALL)



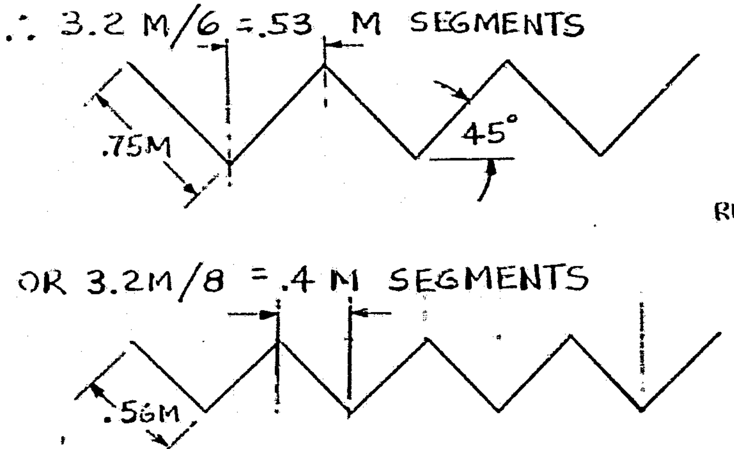
NOTE: ALTERNATE SYSTEM, INFLATABLE; PNEUMATIC DEPLOY & LOCKS TO [illegible].

"W" TROUGH DESIGN EVALUATION

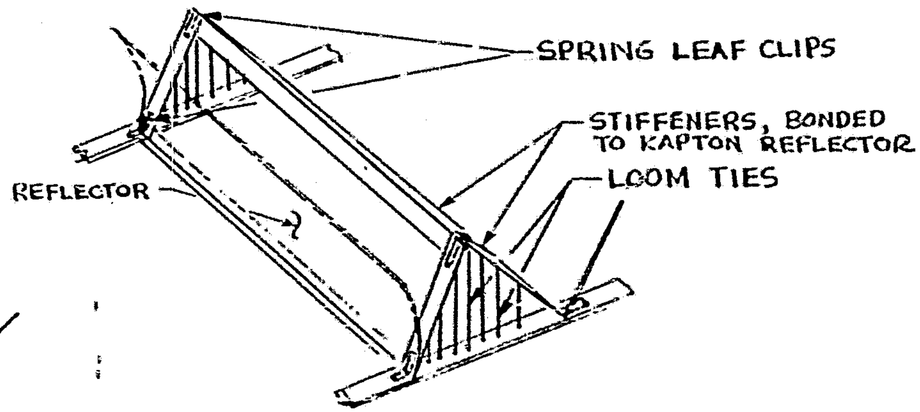




REFLECTOR SIZING



REFLECTOR FRAME SPACEWORK



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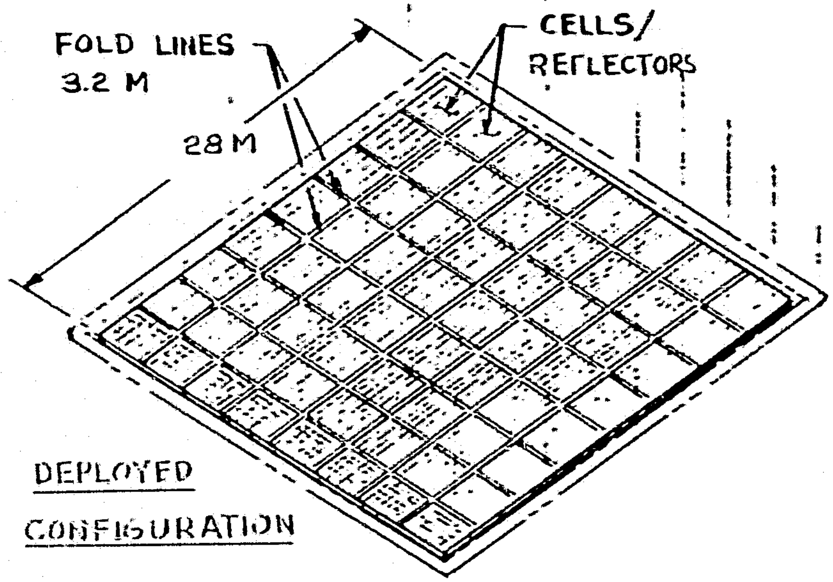
OF POOR QUALITY

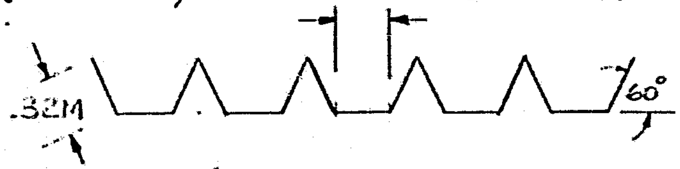
TROUGH VARIATION EVALUATION

TROUGH CR = 2

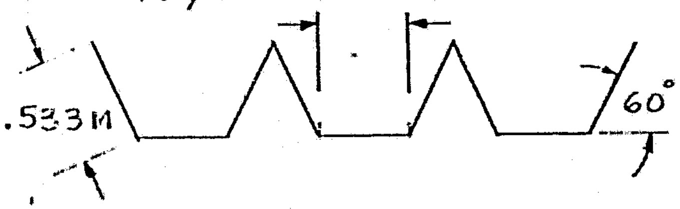


REFLECTOR SIZING

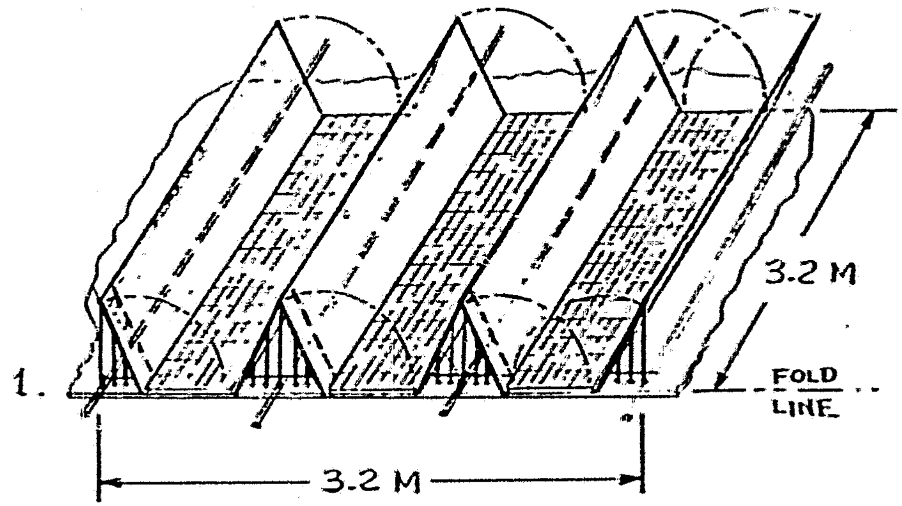
∴ 3.2 M / 10 = .32 M SEGMENTS



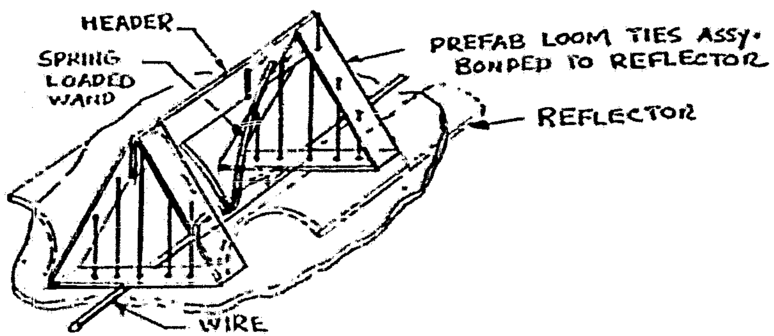
OR 3.2 M / 6 = .533 M SEGMENTS



TROUGH

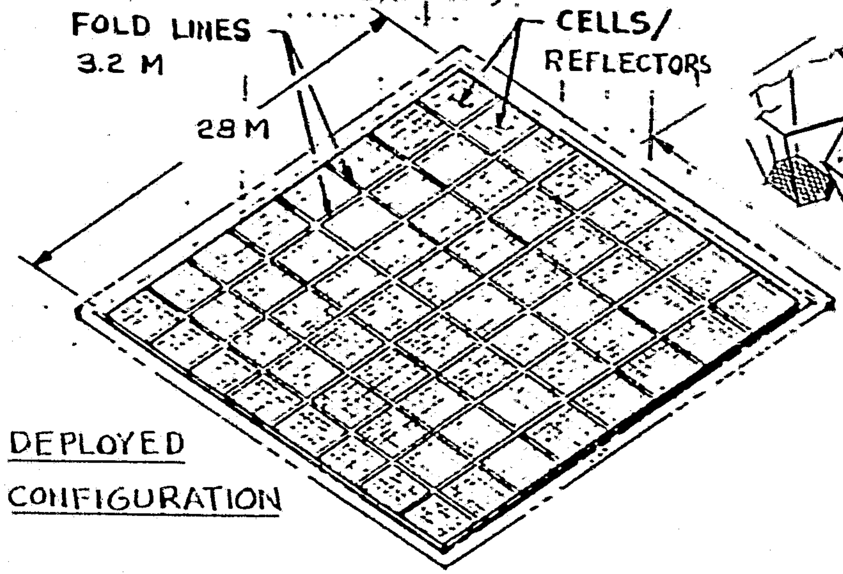


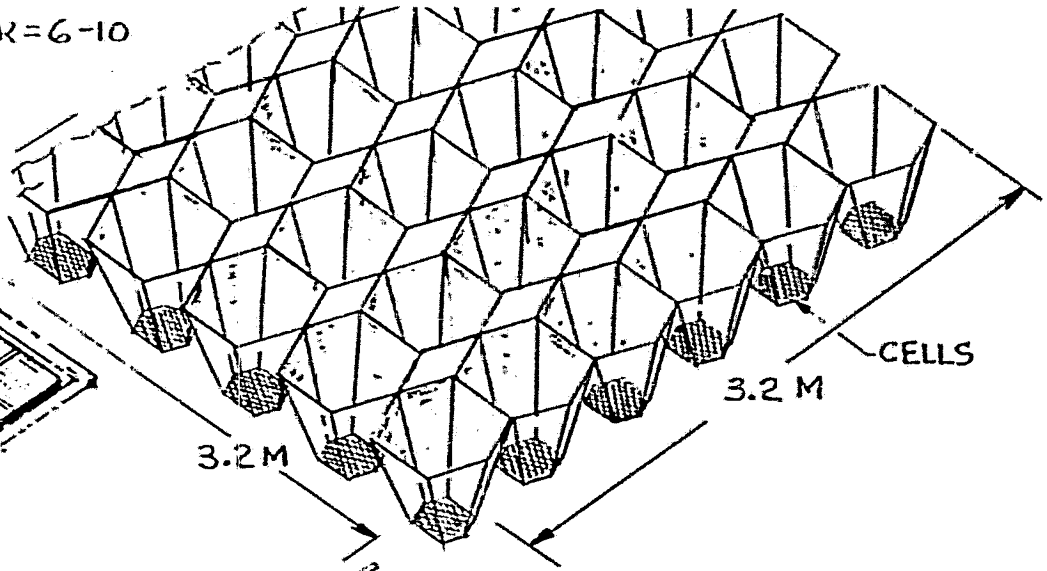
STOWAGE FOLDS

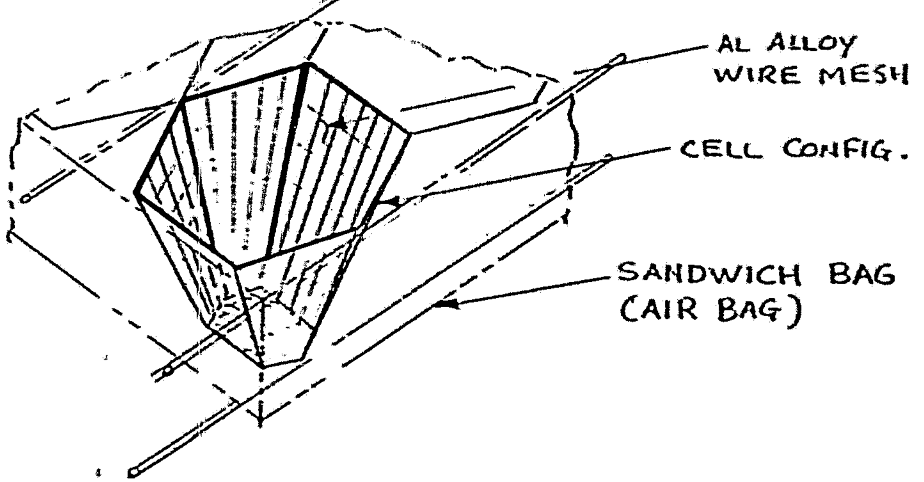


MULTICELL EVALUATION; TRUNCATED HEXAGONAL, CONIC

MULTI-CELLS : HEX, PARABOLIC CR=6-10

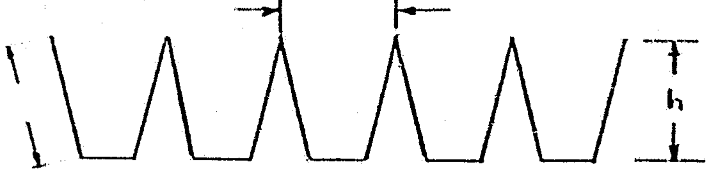




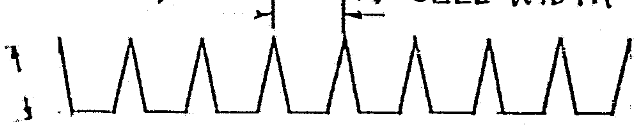


REFLECTOR SIZING

∴ 3.2 M / 5 = .64 M CELL WIDTH

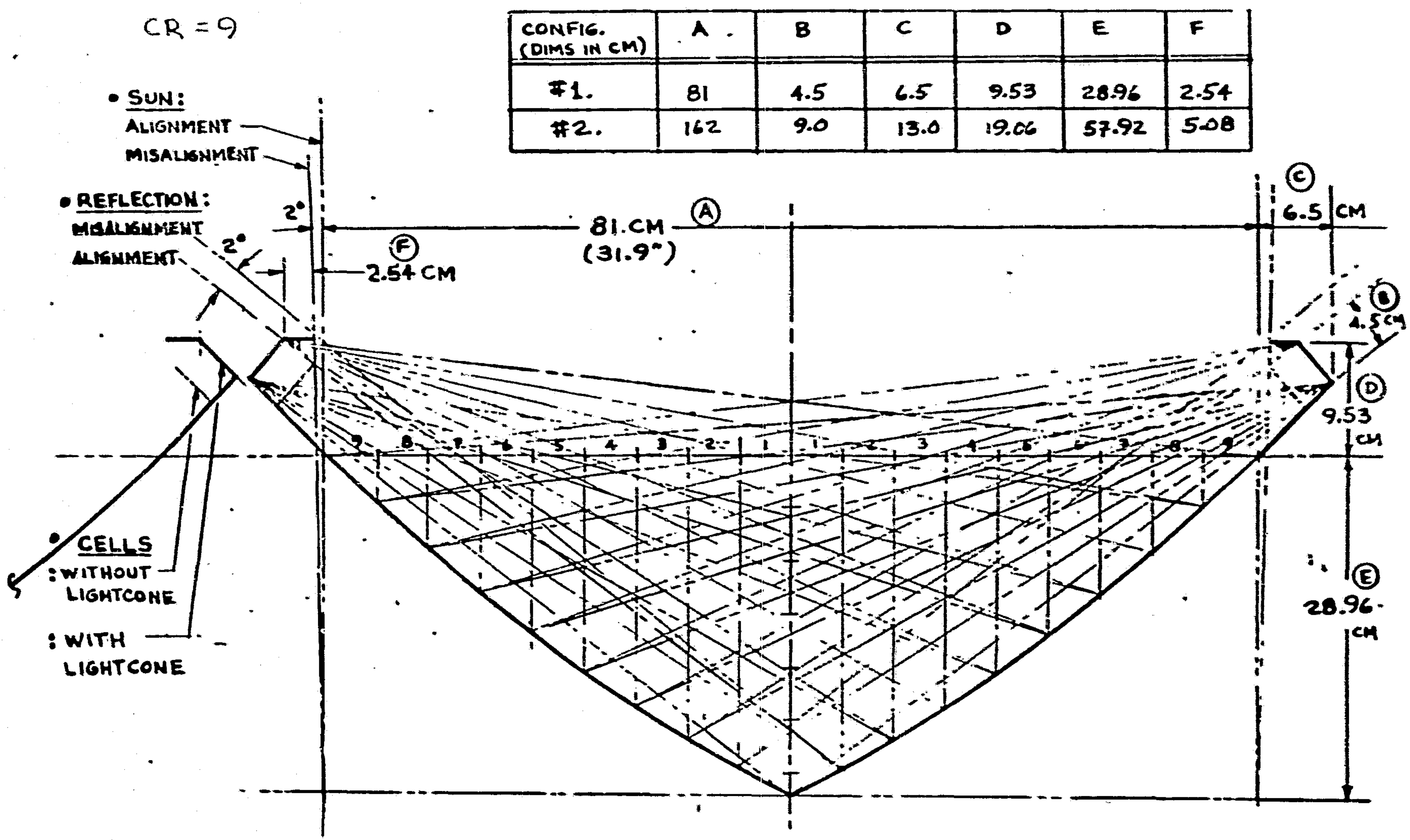


OR 3.2 M / 8 = .4 M CELL WIDTH

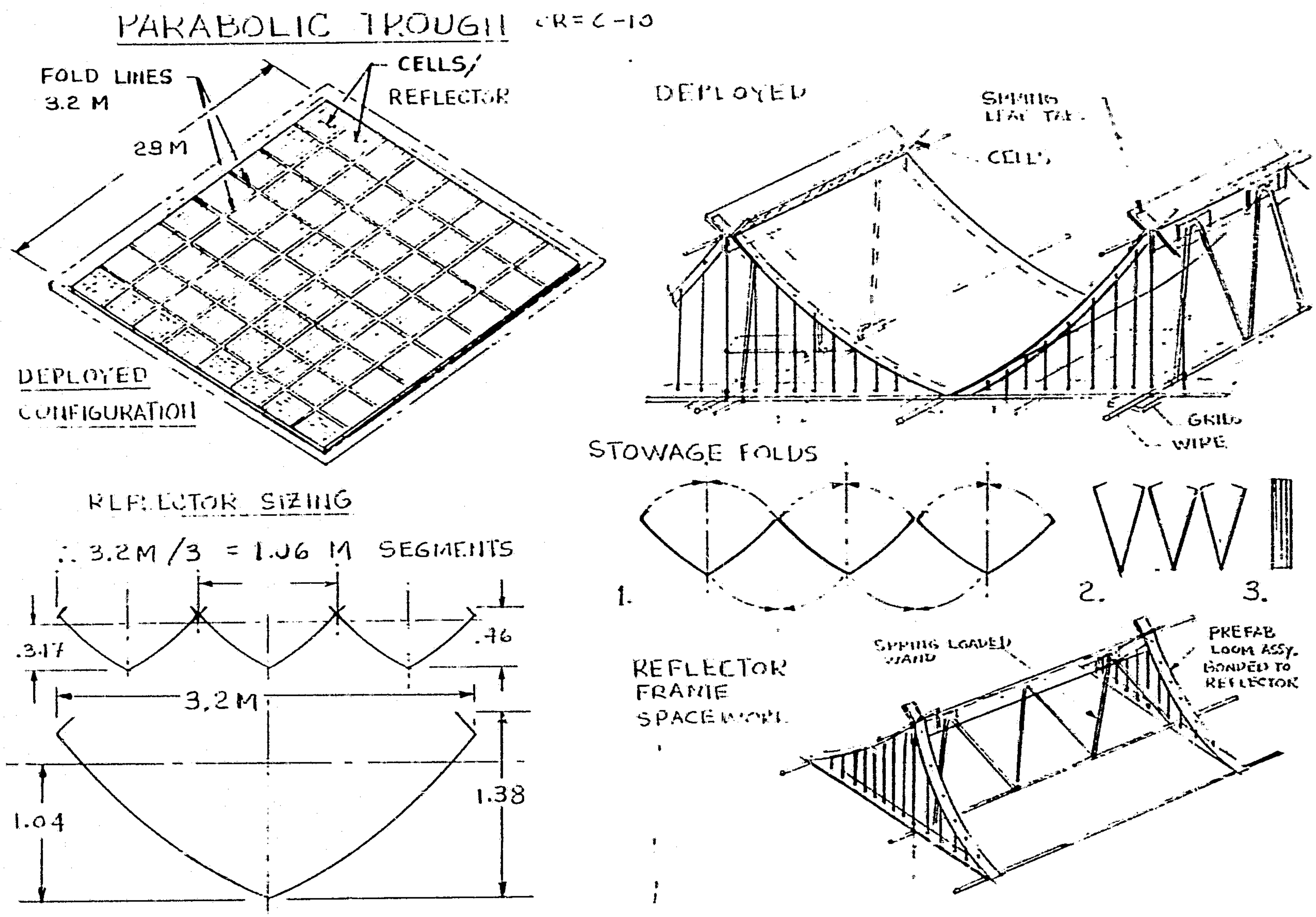


PARABOLIC TROUGH WITH LIGHTCONE

CONFIG. (DIMS IN CM)	A	B	C	D	E	F
#1.	81	4.5	6.5	9.53	28.96	2.54
#2.	162	9.0	13.0	19.06	57.92	5.08



PARABOLIC TROUGH DESIGN EVALUATION



OF POOR QUALITY

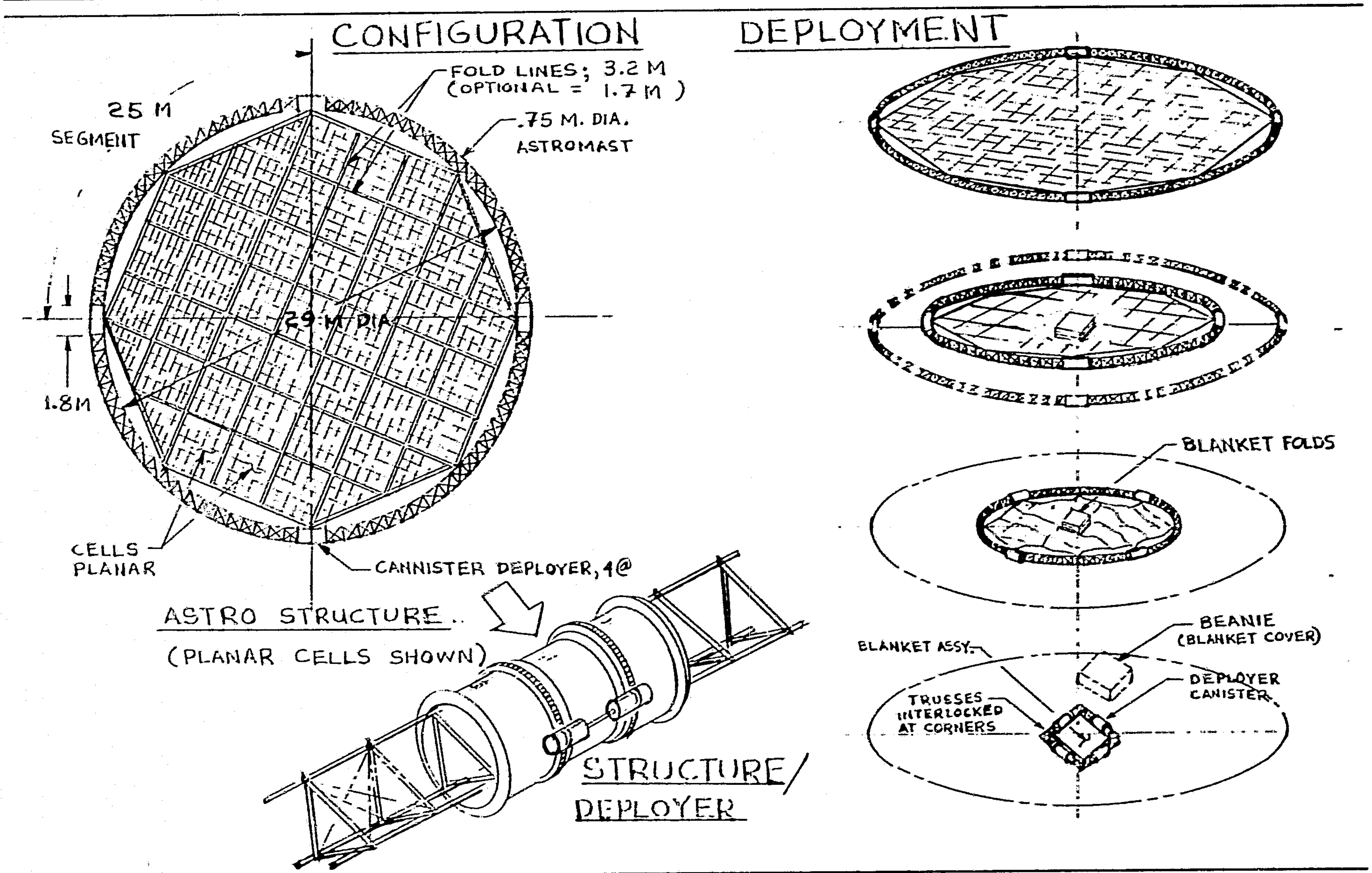
SECONDARY STRUCTURAL SYSTEM CANDIDATE COMPARISONS (CONCENTRATOR REFLECTORS)

CONCEPT \ IMPACT (SYSTEM)	CR	REFLECTOR/ARRAY WEIGHT (KG/M^2)	STOWAGE (1)		DEPLOYMENT			
			M^3	PAYLOAD LENGTH M (2)	ROLLUP	FOLDUP	ERECTABLE AIDS	GRADING 1-10 10 = BEST COMPLEXITY
PLANAR	1	0 (INCLUDED IN ARRAY BLANKET	5	0.4		X		10
"W" TROUGH	1.4	0.14	6.5	0.6		X		8
60-DEG FLAT TROUGH	2	0.21	8	0.7		X		8
SAWTOOTH TROUGH	4	0.24	13	1.0		X	X	6
PARABOLIC TROUGH	6-10	0.22	12	0.8		X		7
CONIC-HEX	6-10	0.20	12	0.9		X		8
FRESNEL MIRROR	6-10	0.28	22	2.0		X	X	4
CASSEGRAIN	10	0.30	28	2.3		X		5
PARABOLOIDAL	10	0.32	30	2.6		X		4
WHIRL CONCENTRATOR	10	0.10	16	0.5	X		X	3

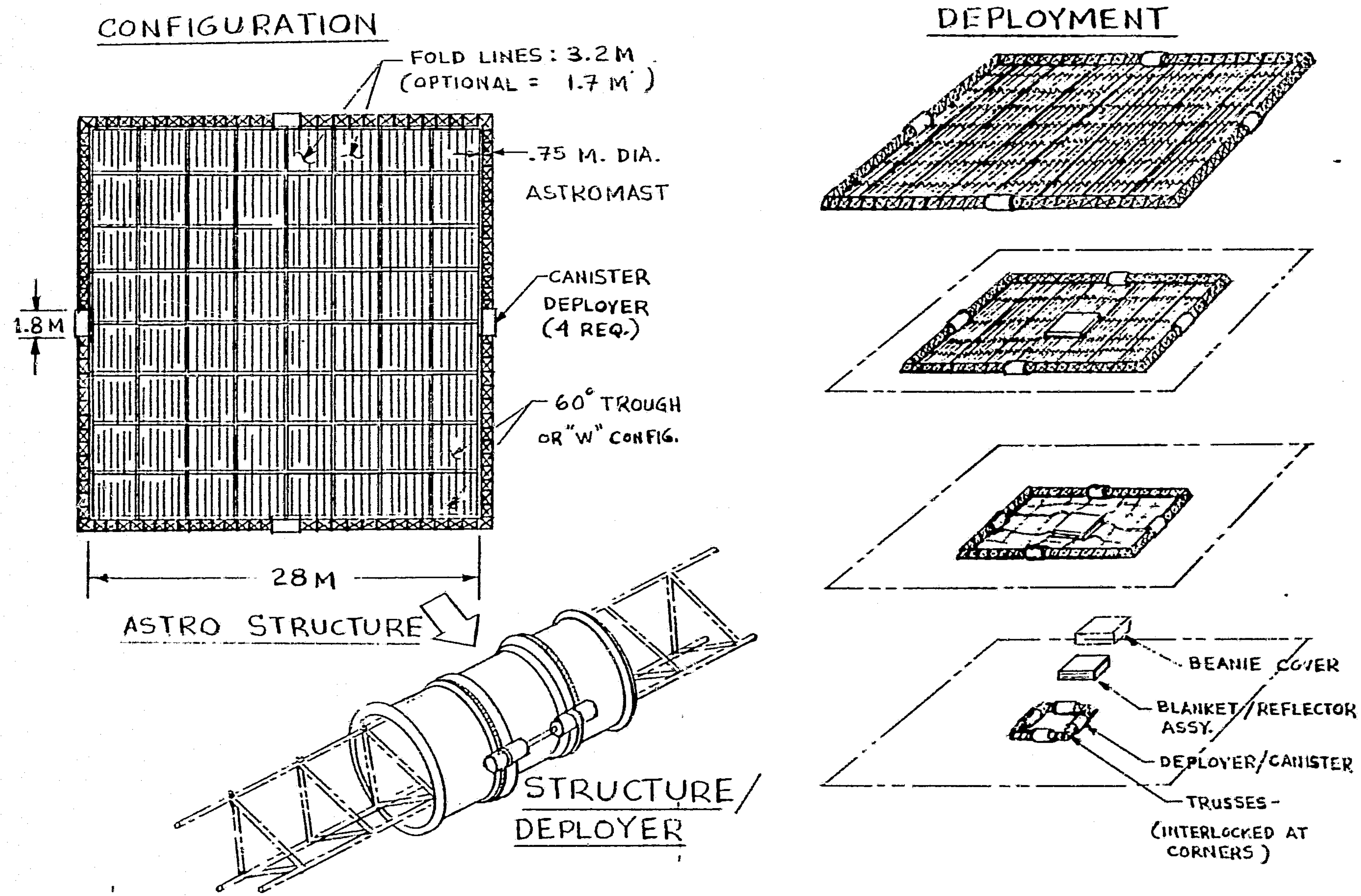
(1) STOWAGE BASED ON AREA OF 600 M^2, & 3.2 X 3.2 METER FOLDS

(2) DEDUCT 0.7 METER OF STOWED LENGTH WHEN STOWING WITHIN ASTRO STRUCTURE

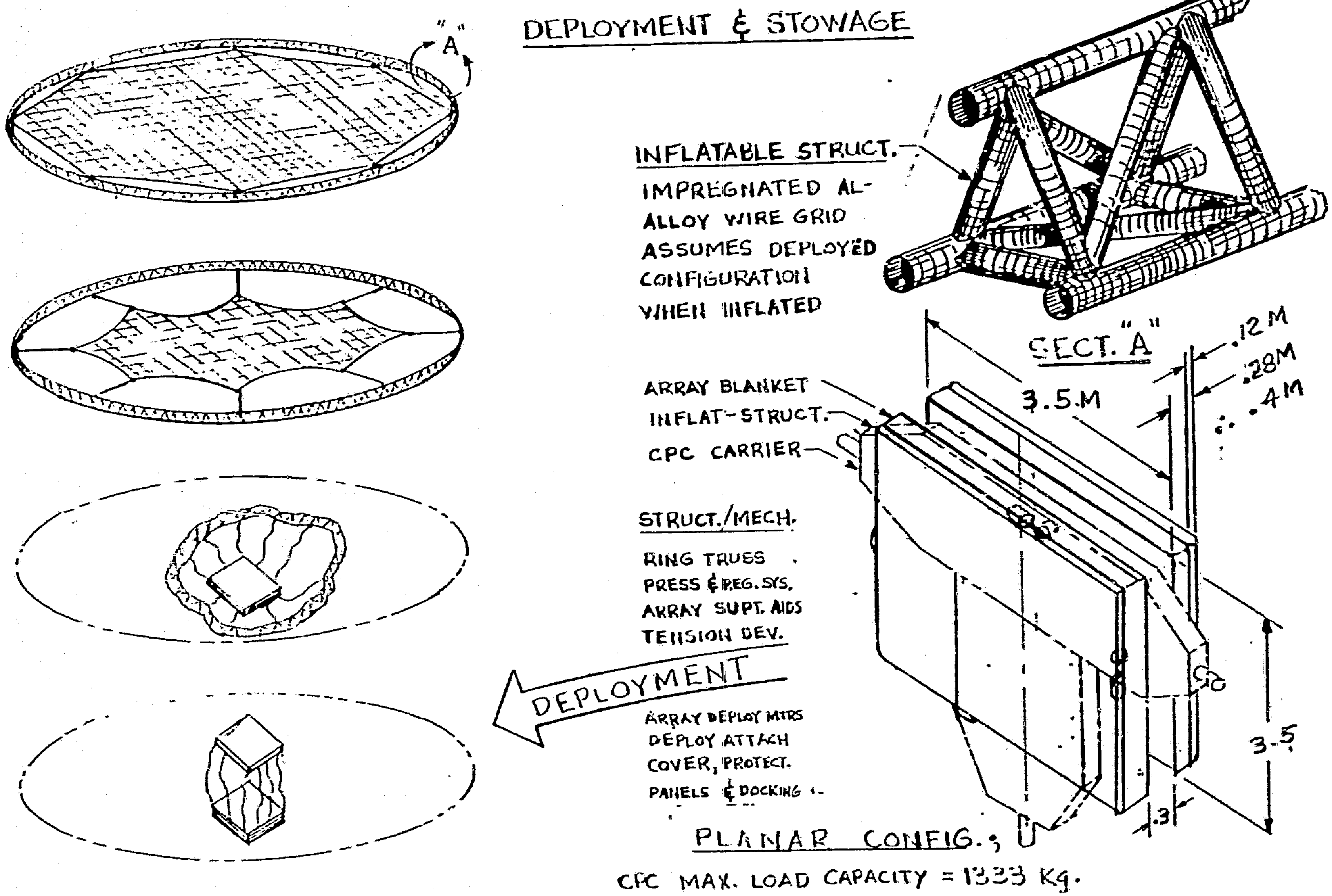
ASTROSTRUCTURE RING TRUSS CONCEPT
(WITH CATENARY BLANKET)



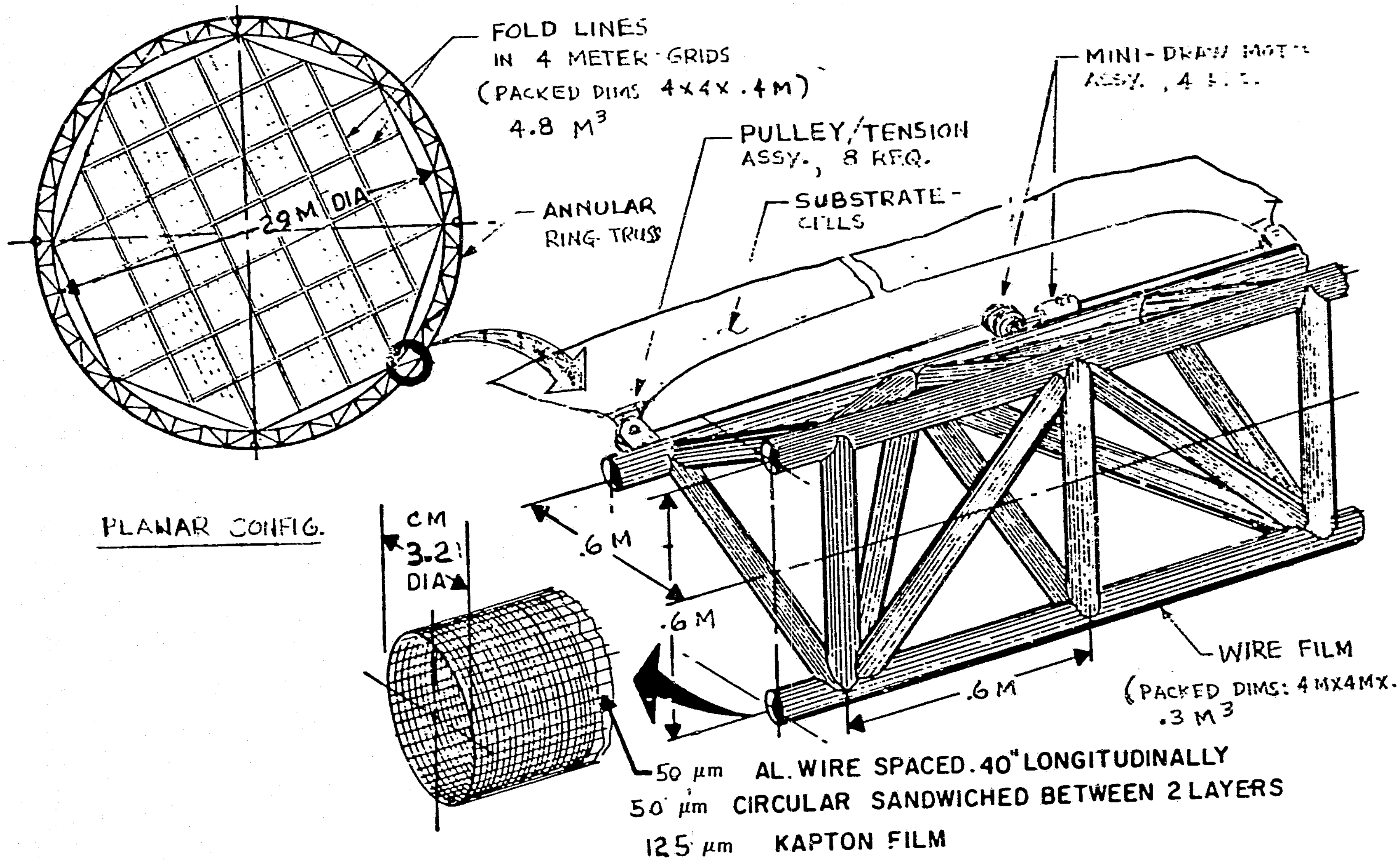
ASTROSTRUCTURE SQUARE TRUSS CONCEPT
(WITH CATENARY BLANKET)



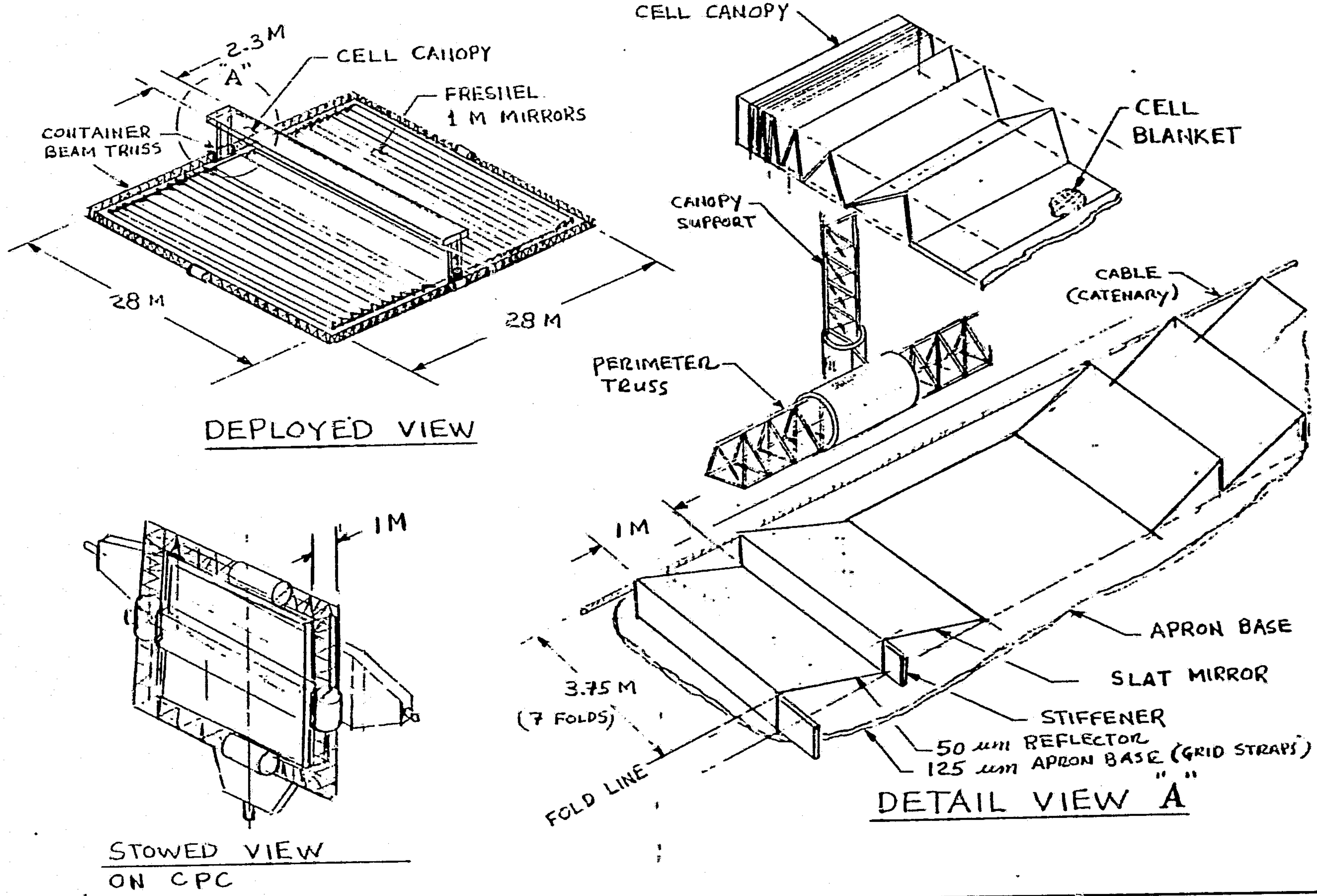
INFLATABLE RING TRUSS WITH A PLANAR CONFIGURATION: 600 M^2



INFLATABLE/RIGID LOC SYSTEM

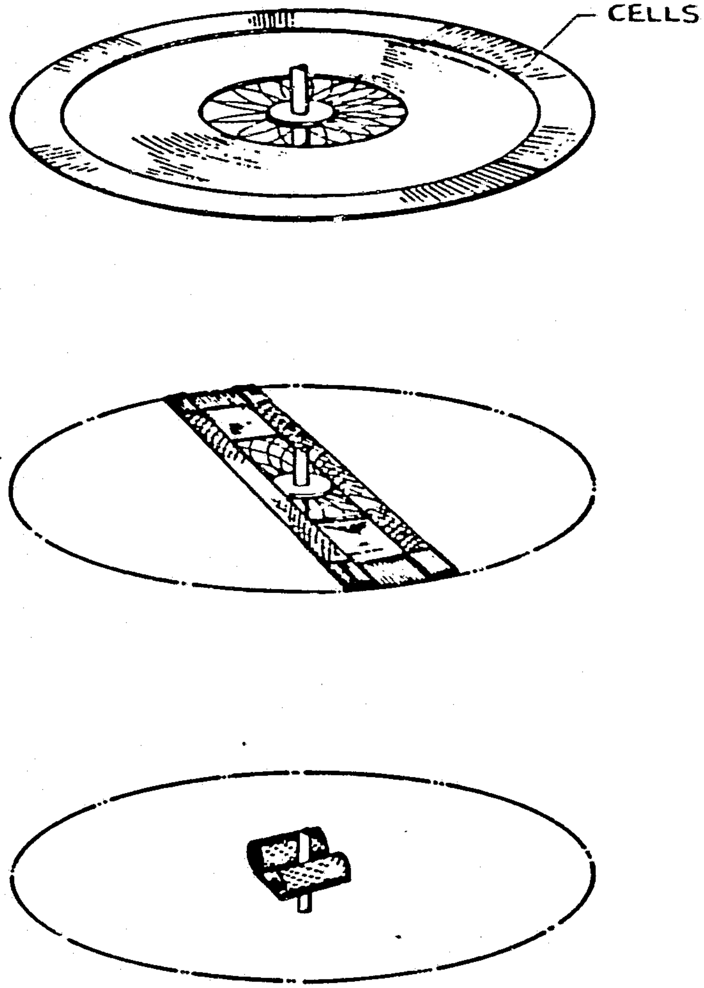


FRESNEL SLAT MIRROR CONCEPT
(SHOWN ON CATENARY PERIMETER TRUSS FRAME)

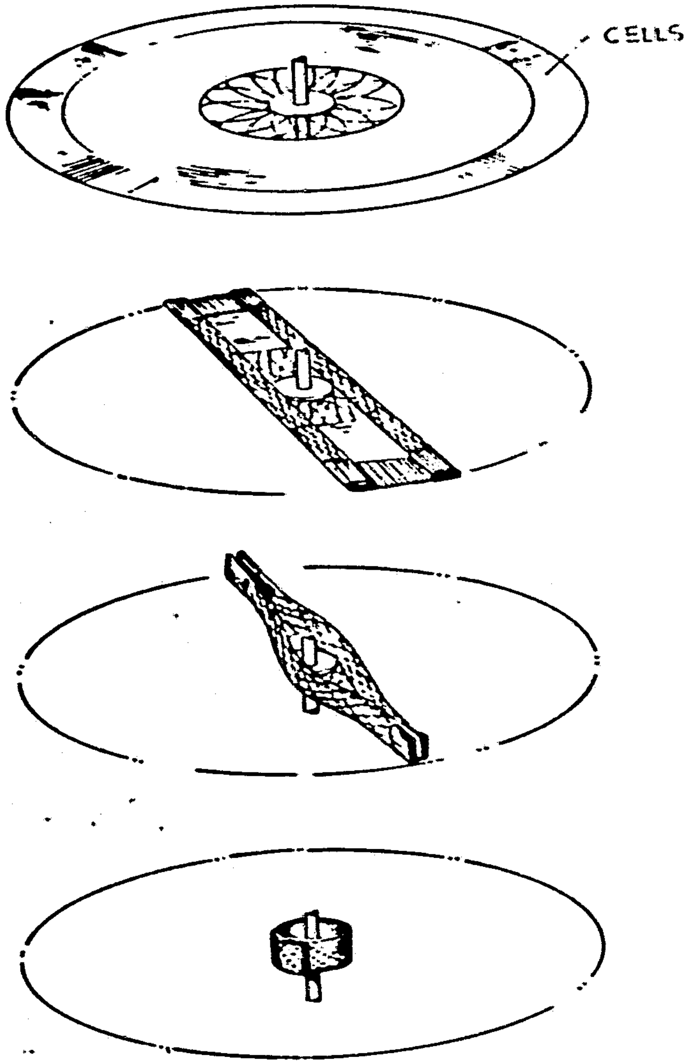


STOWAGE OF SPIN STRUCTURES CONCEPT

Folding of reflector into double roll.

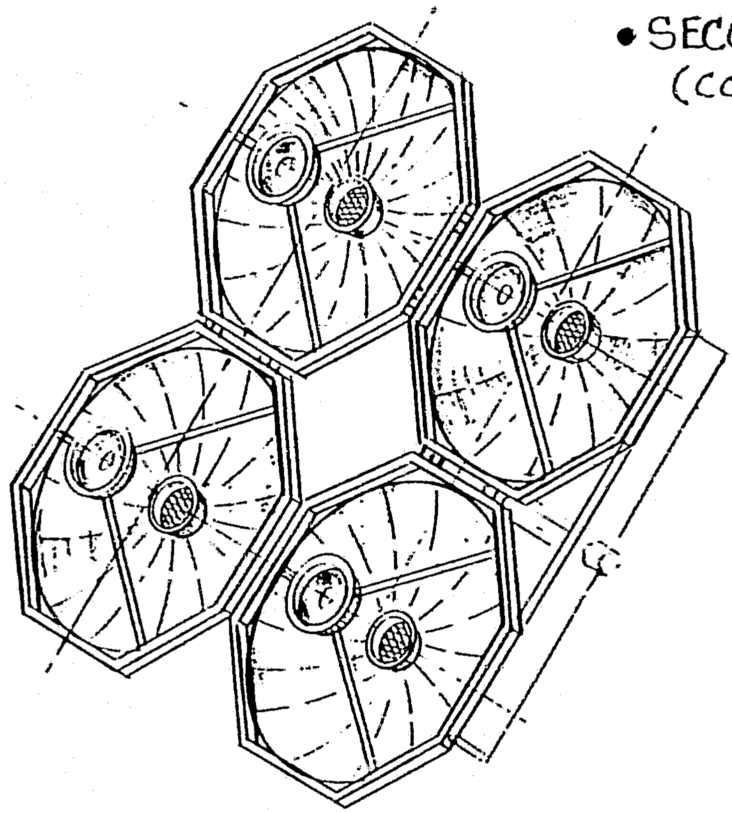


Folding of reflector into toroidal package.



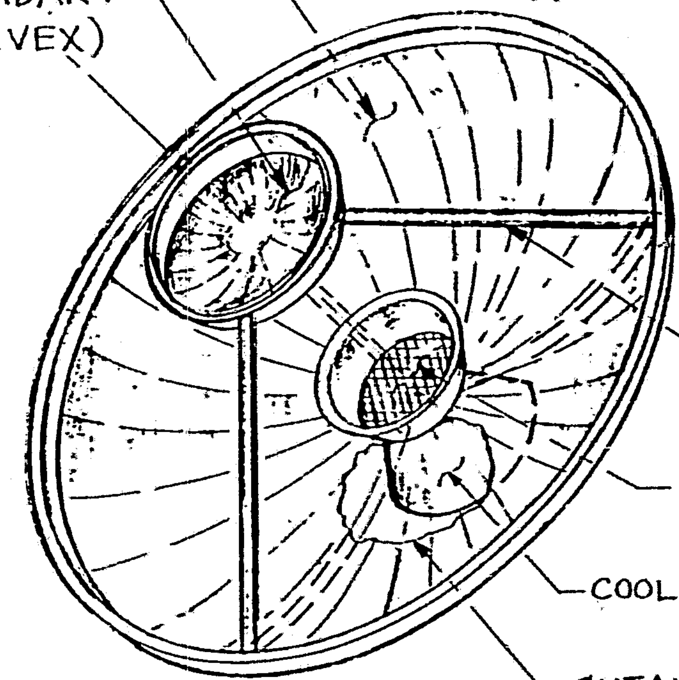
SOLAR CONCENTRATION DESIGN STUDIES

- CASSEGRAIN



CLUSTER OF 4 MODULES

MIRROR
- PRIMARY (28 M DIA.)
- SECONDARY (CONVEX)

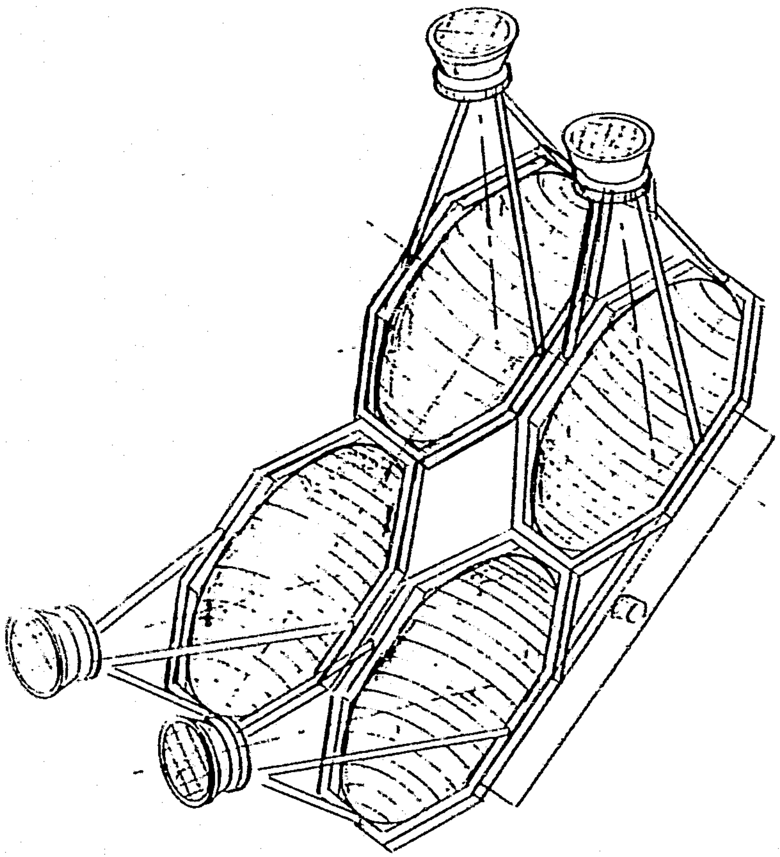


CR = 10:1
(600 M^2 MODULE)

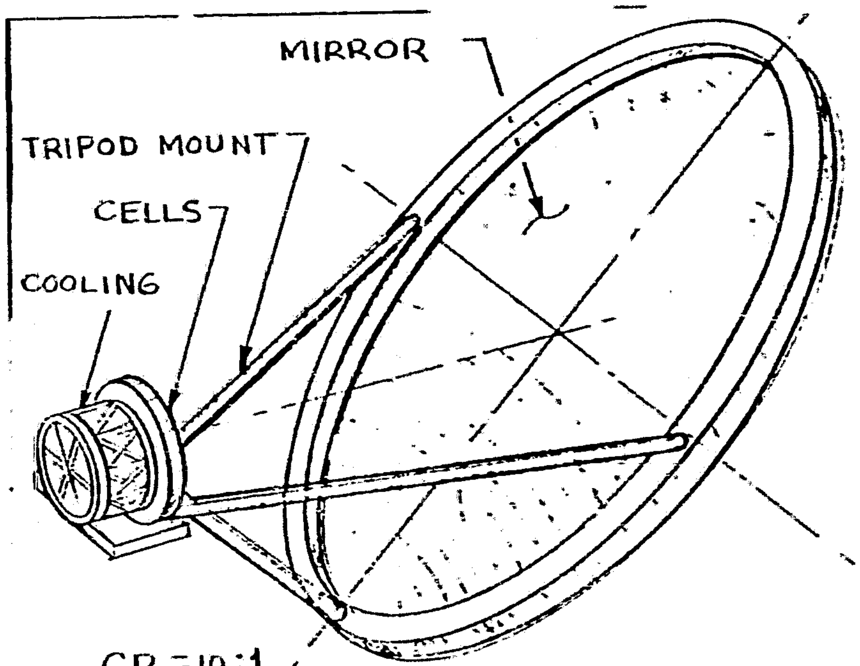
SOLAR CONCENTRATION DESIGN STUDIES

- PARABOLOIDAL
  HIGH CONCENTRATOR

STRUCT:
REFLECTOR
REFLECT. SUPT.
CELL SUPT. ASSY.
CONTAINER ASSY.
DEPLOY MECH.

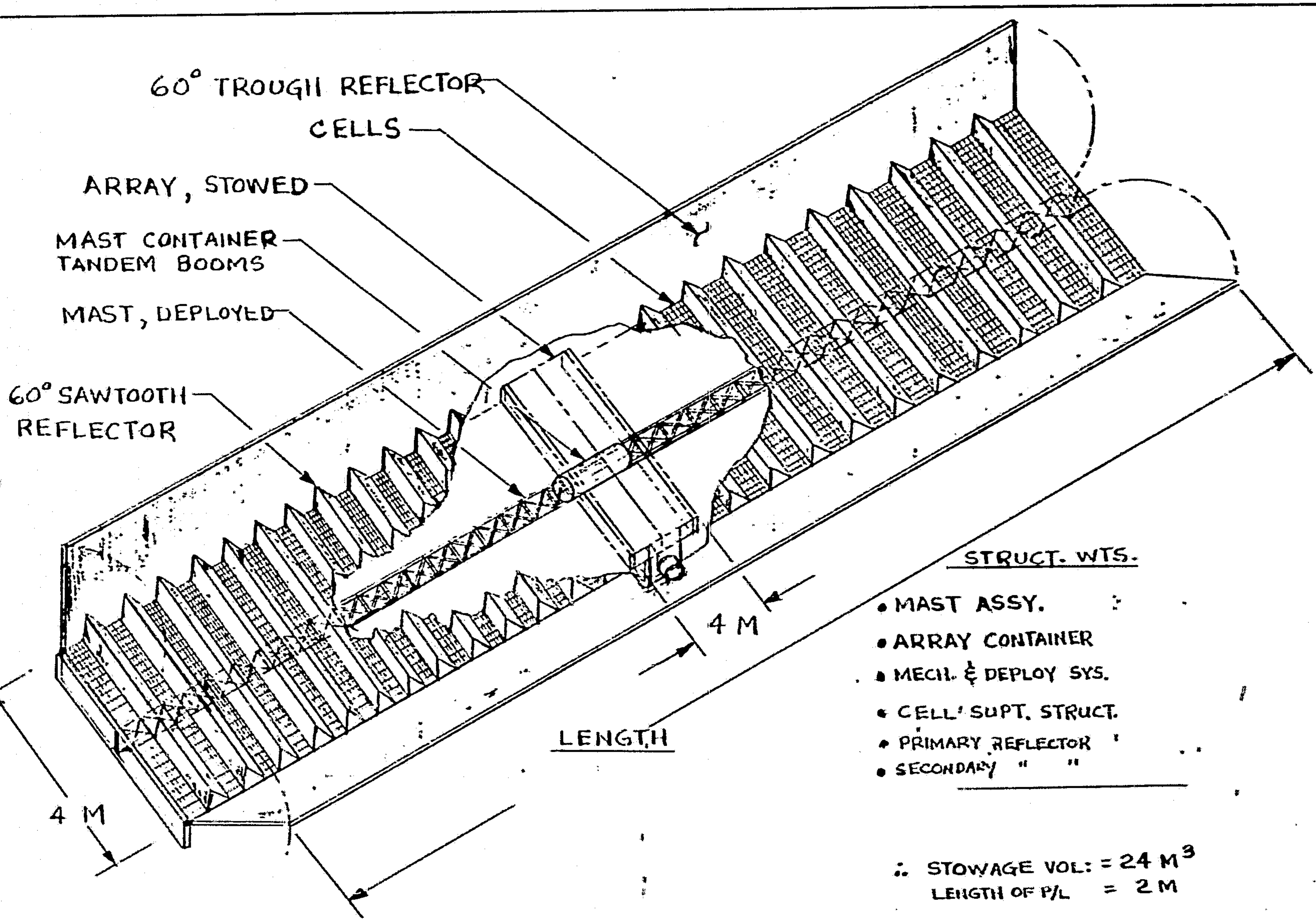


CLUSTER OF 4 MODULE



CR = 10:1
600 M² MODULE

SAWTOOTH TROUGH, CR 4:1

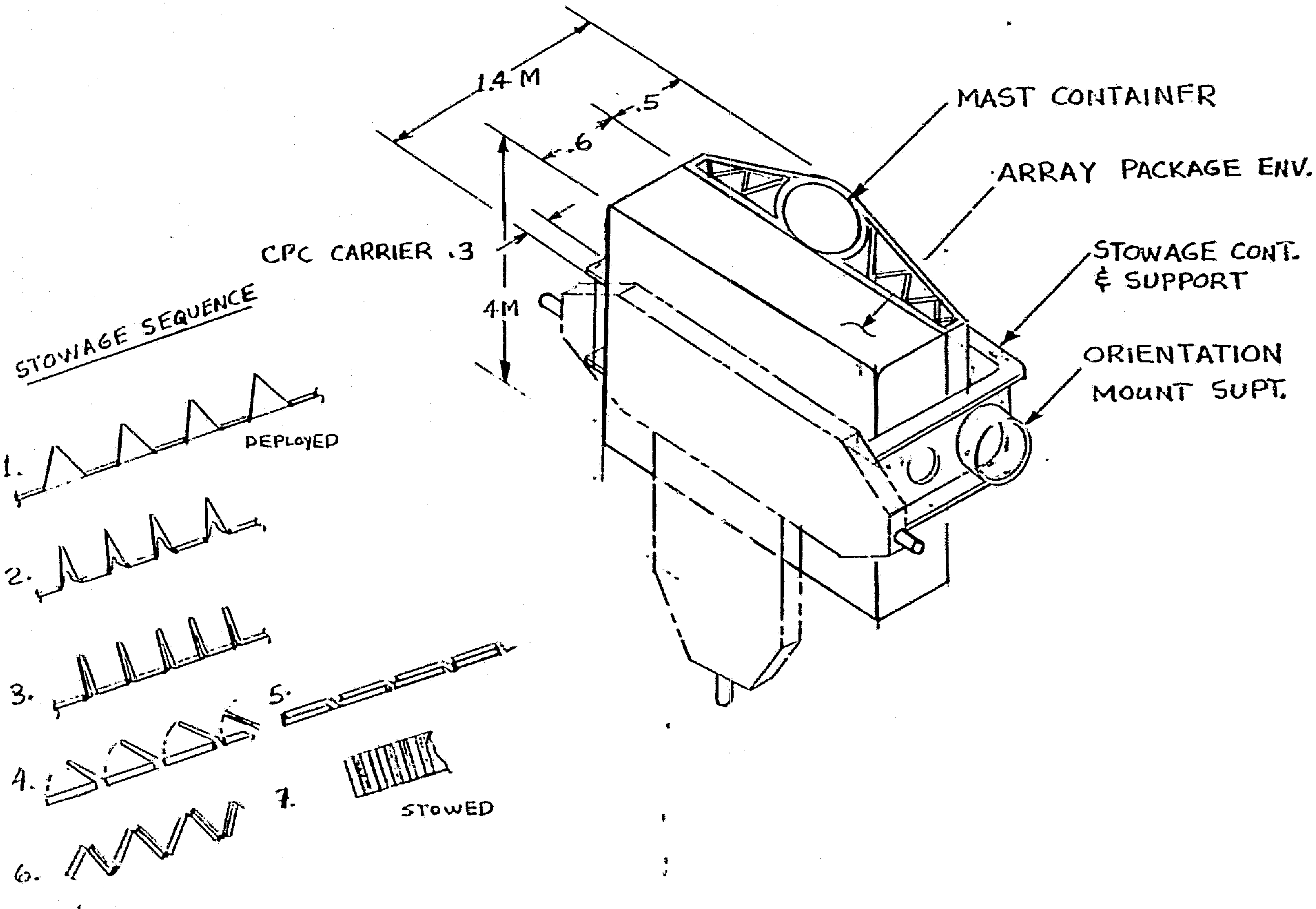


STRUCT. WTS.

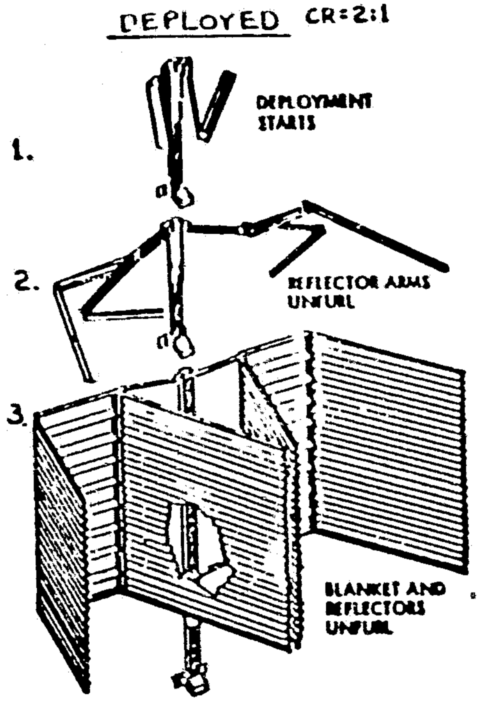
- MAST ASSY.
- ARRAY CONTAINER
- MECH. & DEPLOY SYS.
- CELL SUPT. STRUCT.
- PRIMARY REFLECTOR
- SECONDARY " "

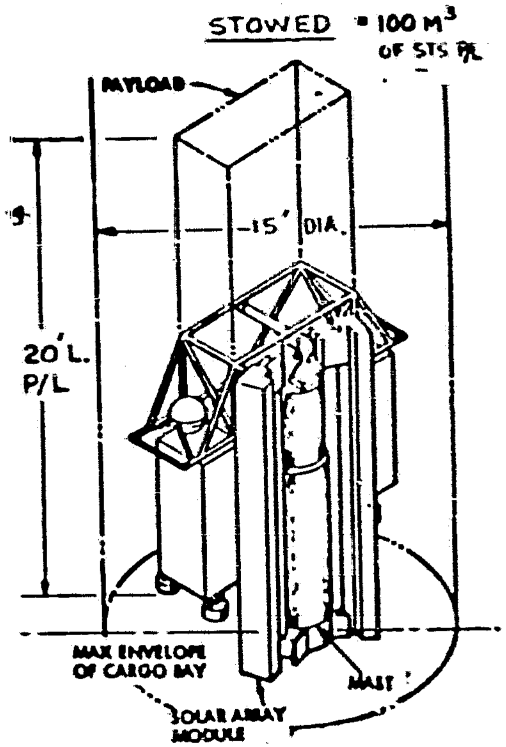
∴ STOWAGE VOL: = 24 M^3
LENGTH OF P/L = 2 M

SAWTOOTH TROUGH PACKAGED

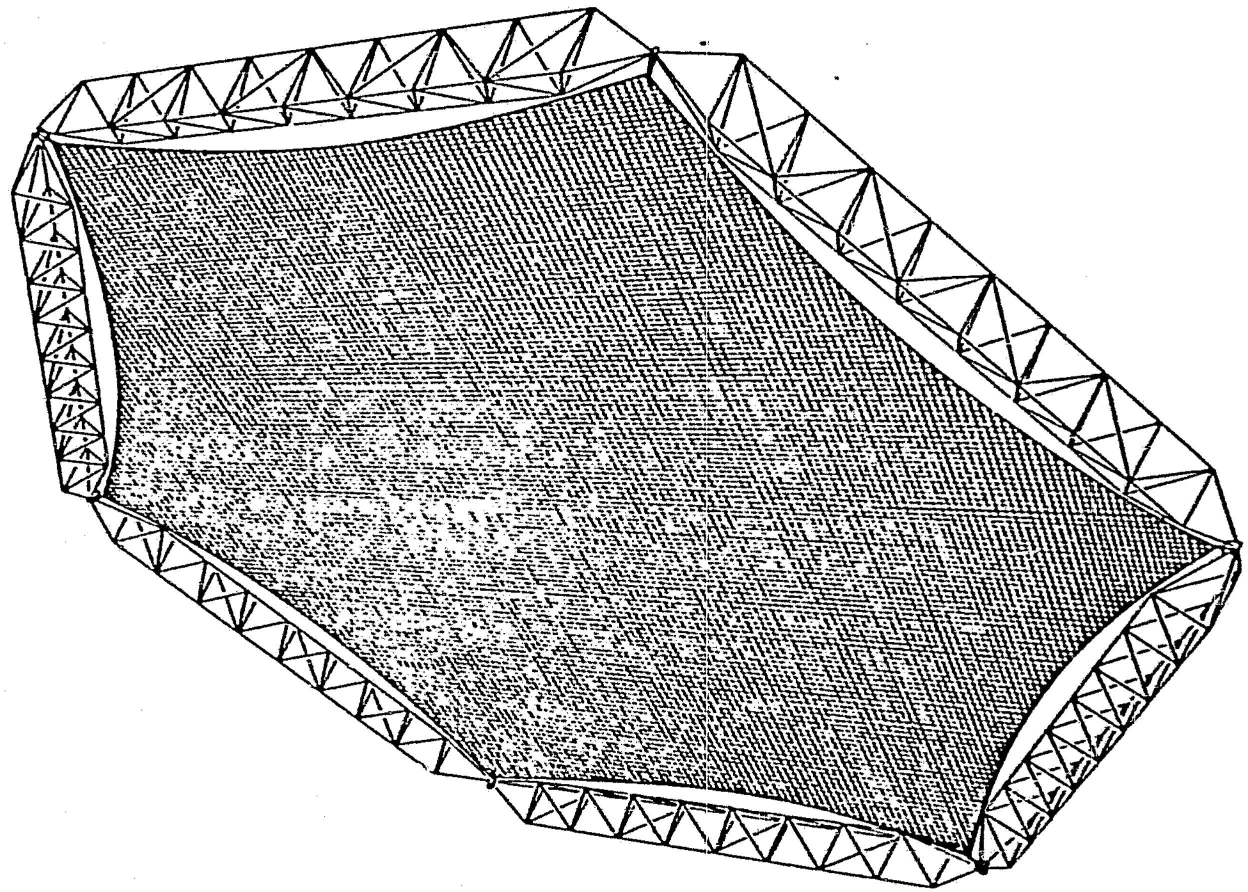


UNFURL LOCKHEED TYPE; 250 KW

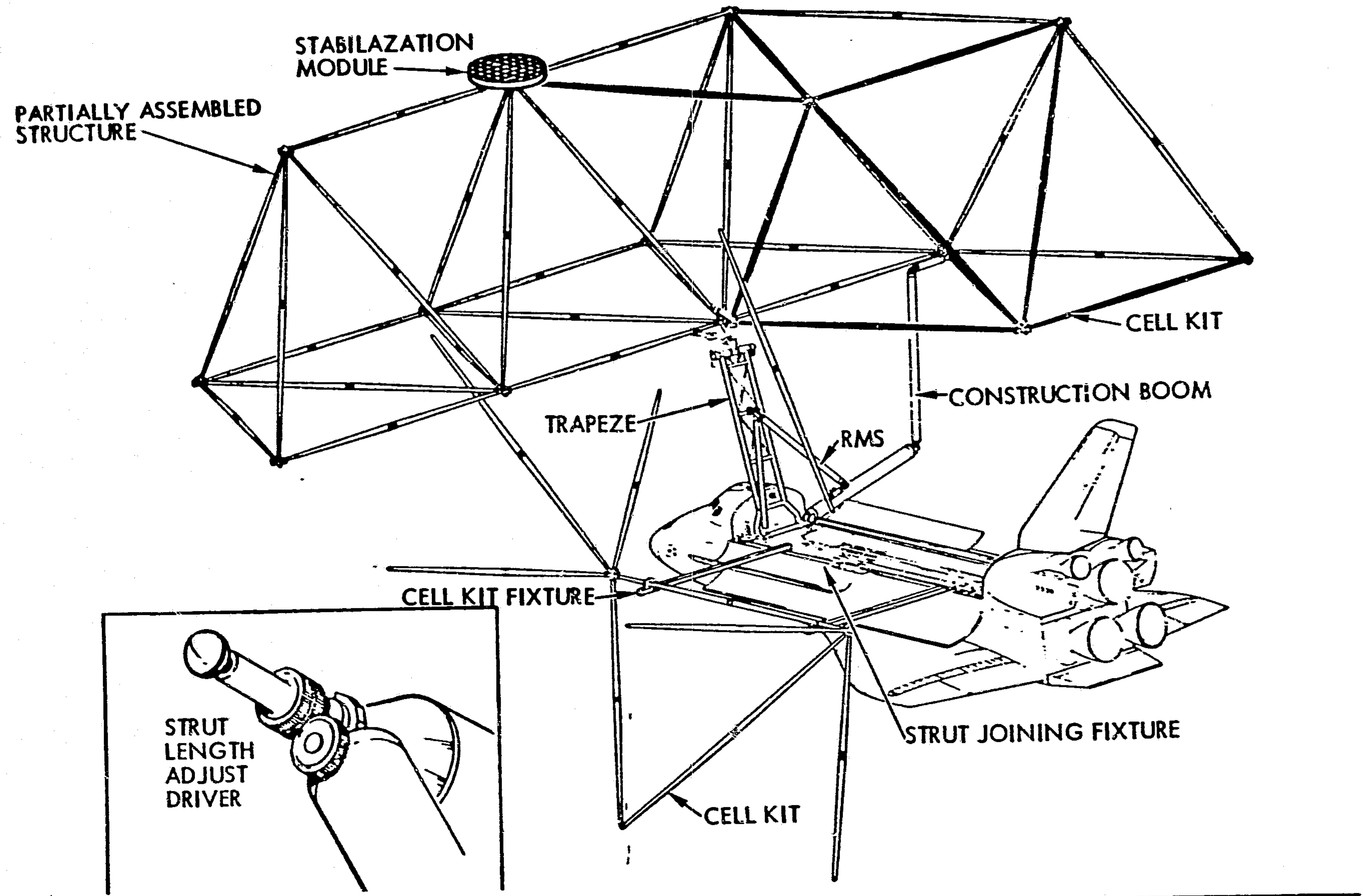




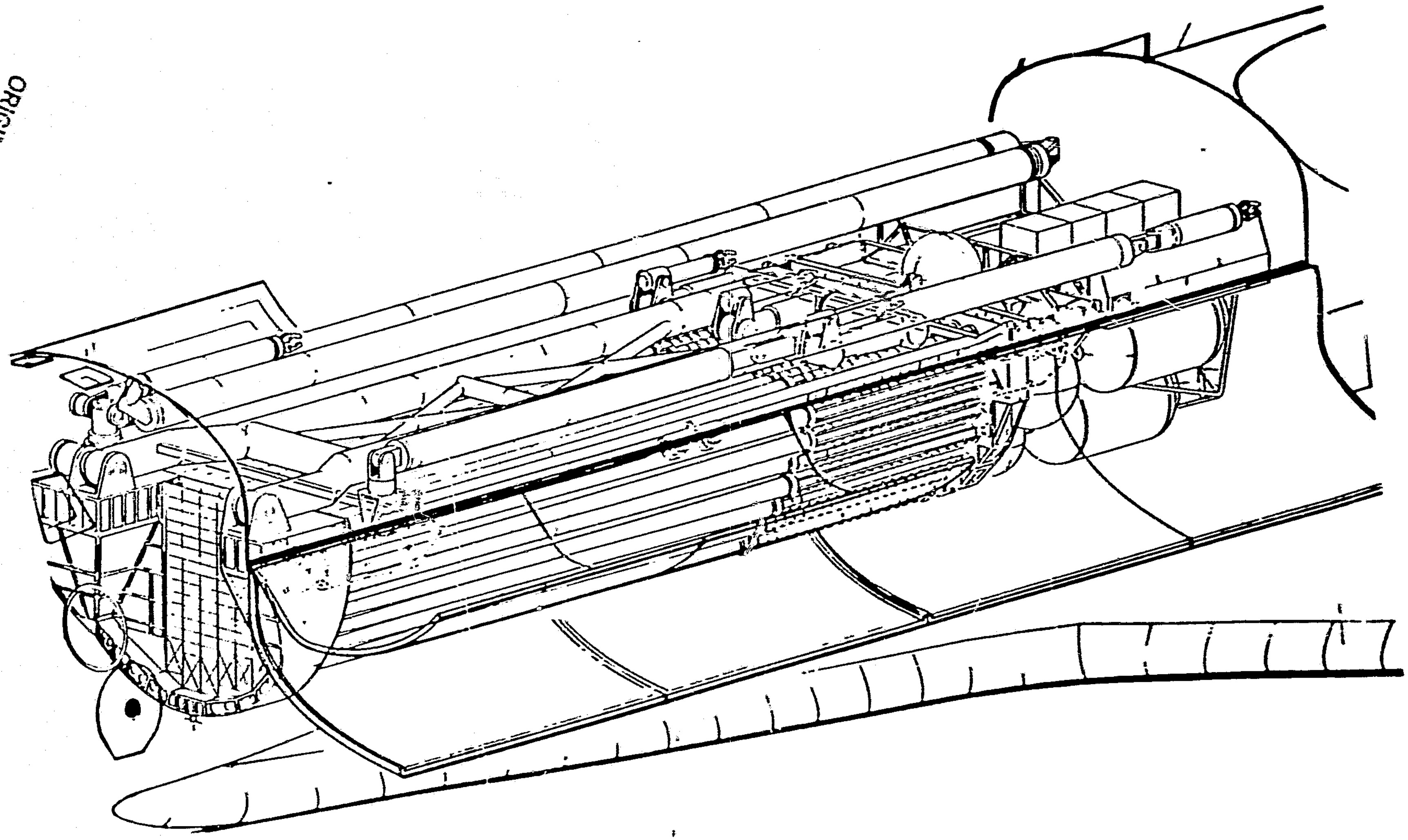
TETRAHEDRAL STRUCTURE (ERECTABLE)



TETRAHEDRAL DEPLOYMENT AND CONSTRUCTION



TETRAHEDRAL STRUCTURE IN PAYLOAD BAY



DEPLOYABLE BOOM MASTS

25-M LENGTH BOOMS (DIMS IN METERS)

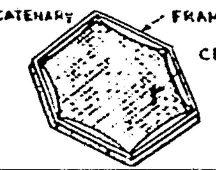
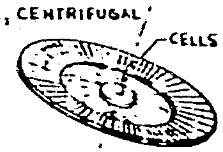
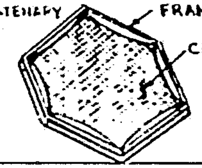
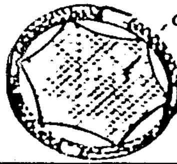
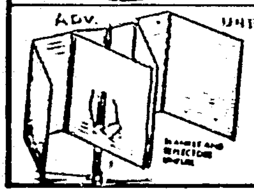
MAST DIA	COMPRESSIVE STRENGTH (NEWTONS)	WEIGHT (KG)		HEIGHT MAST COLLAPSED	CANISTER EST HEIGHT 2.5 RATIO	CANISTER DIA	COST IN $K ⚠1
		MAST	CANISTER				
0.36 (SEPS)	0.190	3.0	3.5	0.5	1.3	0.45	60
0.52	0.240	5.3	3.3	0.3	1.3	0.60	60
0.65	0.376	8.2	4.1	0.3	1.6	0.75	62
0.78	0.541	11.8	5.9	0.3	2.0	0.90	63
0.90	0.736	16.1	7.6	0.5	2.3	1.05	64

DATA FURNISHED 23 MAY 1979 BY: ASTRO-RESEARCH CORP., CARPINTERIA, CA
ABLE ENGINEERING, GOLETA, CA

⚠1 NOTE: PRICING FOR SYSTEM UP TO 3.5-M-DIAMETER NEGLIGIBLE

⚠1 PLUS $10,000 PER CANISTER AFTER FIRST UNIT; VENDOR EST

PRIMARY STRUCTURE SYSTEM CANDIDATE COMPARISONS
(ENVELOPE OF STRUCTURE)

CONCEPT \ IMPACT SYSTEM	STRUCT WEIGHT (KG/M^2) (FOR AREAS SHOWN) 300	600	900	1200	1800	STOWAGE VOLUME (M^3)	PAYLOAD LENGTH (M)	DEPLOYMENT REQMT AIDS	ERECTABLE CONST	AUTONOMY	STS WAIT (HR)
TETRAHEDRAL ERECTABLE CATENARY FRAME CELLS 	0.60	0.52	0.46	0.44	0.38	130^{+} / 100-250 KW 1/2 ALL	10 / P/L BAY	TRAPEZE FIXTURE	YES STS HOLD & CREW	NO	28-48
SPIN, CENTRIFUGAL CELLS 	0.22	0.21	0.21	0.20	0.20	5	0.4		REQUIRES SPIN SYS	YES	C/O ONLY
INFLATABLE POLYGON CATENARY FRAME CELLS 	0.36	0.38	0.42	0.46	0.50	6	0.5			YES	C/O ONLY
CELLS ASTRO PLANETARY 	0.21	0.21	0.21	0.22	0.24	8	0.8			YES	C/O ONLY
ADV. UNFURL 	[illegible].70	0.60	0.60	0.60	0.58	35	6.1	RMS MIN		YES	12-24

PRIMARY AND SECONDARY STRUCTURES EVALUATION

	PRIMARY & SECONDARY SYSTEM CANDIDATES	DEPLOYMENT					SYSTEMS			STOWAGE		EFFECTIVENESS (1)			SELECTION (2)	
		CR	FOLDUP	ROLLUP	ERECTABLE	AUTONOMY	COMPLEXITY	RELIABILITY	COMPATIBILITY REFLECT/STRUCT.	VOL.	LENGTH P/L BAY	COOLING IMPACT	CELL REQMT. IMPACT	SYSTEM KG/M^2	COSTING FACTOR	ORDER OF PREFERENCE
REFLECTORS	PLANAR	1	10	8		10	10	10	10	10	10	10	10	.0	10	1
	"W" TROUGH	1.4	8	6		9	8	6	7	8	8	9	4	.14	8	3
	60° FLAT TROUGH	2	8	5		9	8	8	9	8	8	9	7	.21	7	2
	SAWTOOTH TROUGH	4	4	1		4	5	4	5	4	4	8	4	.24	3	6
	PARABOLIC TROUGH	10	4	1		5	5	4	4	5	6	7	6	.21	4	4
	CONIC/HEXAGONAL	8	5	5		7	6	5	5	5	6	6	6	.20	5	5
	FRESNEL MIRROR	10	3	3		5	5	4	3	3	5	8	10	.28	2	7
	CASSEGRAIN	10^+	3	3		5	2	4	4	3	5	8	10	.30	2	8
	PARABOLOIDAL DISH	10^+	2	2		4	2	4	3	3	5	7	10	.32	2	10
	WHIRL CONCENTRATOR	10^+	7	5		3	1	3	4	10	10	2	10	.10	3	9
STRUCTURE	TETRAHEDRAL		1	1	X	0	1	8	10	1	1			.50	1	5
	SPIN CENTRIFUGAL		9	8		8	3	5	7	10	10			.21	7	3
	INFLATABLE RING TRUSS		10	8		7	5	8	10	10	10			.49	6	2
	ASTRO MAST PLANETARY		8	4		10	8	10	10	8	9			.21	10	1
	UNFURLABLE		4	4		6	2	7	8	4	3			.60	3	4

(1) VALUES BASED ON 600 M^2

(2) ORDER OF PREFERENCE: NO. 1 NUMERICALLY HIGHEST.

(3) ALL OTHER VALUE RATINGS FROM 1-10 INDICATE 10 AS HIGHEST.

PRIMARY STRUCTURE DESIGN SUMMARY

- CONFIGURATION
  - CIRCUMFERENTIAL RING & RECTANGULAR PERIMETER TRUSSES CONSIDERED

- CANDIDATES
  - ASTROTRUSS/BEAM MACHINE, SPIN/WHIRL, INFLATABLE, UNFURLABLE, & TETRAHEDRAL ERECTABLE

- SELECTION
  - <u>ASTROMAST TRUSS</u> - FOR SIZE & NEAR-TERM REQUIREMENTS OF THIS STUDY, THE ASTROMAST TRUSS WAS SELECTED OVER THE BEAM MACHINE BECAUSE IT PROVIDES DEPLOYMENT AUTONOMY, LEAST STOWAGE, & COSTS

  - <u>SPIN/WHIRL</u> - IS EXTREMELY ATTRACTIVE FOR WEIGHT, STOWAGE VOLUME, & COSTS--WAS NOT SELECTED BECAUSE MISSION IS UNKNOWN--THIS CONCEPT NOT AS FLEXIBLE AS A STATIONARY MODULE

  - <u>INFLATABLES</u> - VERY COMPETITIVE SYSTEM IN THE SMALL-TO-MODERATELY SIZED MODULES (300-KW UNITS) FOR AUTONOMOUSLY DEPLOYED STRUCTURES; FOR LARGE SINGLE-CONCENTRATOR DESIGNS REQUIRING AUTONOMY APPEARS TO BE THE BEST CANDIDATE AT PRESENT TIME

  - <u>UNFURLABLE</u> - HAS GOOD STOWAGE & DEPLOYABLE CHARACTERISTICS WITH GOOD HISTORICAL APPLICATIONS BUT IS HEAVY, COMPLEX, & COSTLY

  - <u>TETRAHEDRAL ERECTABLE</u> - ERECTABLE-TYPE STRUCTURE REQUIRING LONG ORBITER STAY TIMES--BECOMES ATTRACTIVE IN SIZES BEYOND THIS STUDY

  - <u>BEAM MACHINE</u> - EXCELLENT FOR LARGER STRUCTURES; WAS NOT CONSIDERED FOR THIS STUDY, WHICH REQUIRES MINIMUM STS PAYLOAD VOLUME & ON-ORBIT STAY IMPACTS

- CONCLUSIONS

  BASIS FOR SELECTION IS AUTONOMY, MINIMUM STS VOLUME & STAY TIMES, SIMPLICITY, RELIABILITY, PRODUCIBILITY, WEIGHT, & COSTS

STRUCTURAL / MECHANICAL CONCLUSIONS / RECOMMENDATIONS

PLANAR SYSTEMS

- ASTROMAST PERIMTER STRUCTURE CONCEPT BEST IN 100 - 300 KW MODULES (BASED ON SIMPLICITY, WEIGHT, STOWAGE AND COST FACTORS)

CONCENTRATOR SYSTEMS

- 60^{o} FLAT TOUGH CONCEPT BEST FOR LOW CONCENTRATION RATIOS (CR = 2)
- CONIC OR PARABOLIC TROUGH BEST FOR INTERMEDIATE CONCENTRATION RATIOS (CR = 2 THROUGH 6)
- PARABOLOIDAL DISH,WHIRL CONCENTRATOR AND CASSEGRAIN CONCEPTS NEED FURTHER EVALUATION FOR HIGH CONCENTRATION RATIOS (CR>6)

BRIEFING OUTLINE

OVERVIEW

- OBJECTIVES
- APPROACH
- GROUNDRULES/REQUIREMENTS

  – S.J. NALBANDIAN

DESIGN CONCEPTS

- SOLAR ARRAY/CELL TECHNOLOGY
  – S.J. NALBANDIAN
- CONCENTRATOR CONCEPTS
  – E.P. FRENCH
- CONFIGURATION TRADES
  - DEPLOYMENT MODES
  - PLANAR
  - CONCENTRATOR
    – J.A. MENAGER

ON-ORBIT MAINTAINABILITY

- SHUTTLE CAPABILITY
- MAINTENANCE TRADES

  – S.J. NALBANDIAN

SUMMARY

- PRELIMINARY CONCLUSIONS
- PLANNED ACTIVITIES

  – S.J. NALBANDIAN

MAINTAINABILITY PHILOSOPHY

GENERAL APPROACH

- REMOVE FAULTY LINE REPLACEABLE UNIT (LRU) & REPLACE IN LIEU OF REPAIR
- LRU MINIMUM SIZE
  - SOLAR CELL PANELS - DEPENDENT ON CONFIGURATION
  - OTHER-NOT LOWER THAN COMPONENT LEVEL
- INDIVIDUAL SOLAR CELLS (AND INTERCONNECT) NOT CONSIDERED LRU'S
  - FAILURE DETECTION IMPLICATIONS
  - DIFFICULTY OF REMOVAL AND REPLACEMENT
- EXCEPTION TO LRU CONCEPT - POSSIBLE IN SITU ADJUSTMENT OF FIGURE SHAPING AND TENSIONING RIGS
- REPLACED UNITS AND OTHER MATERIAL RETURNED TO EARTH TO AVOID PROLIFERATION OF SPACE DEBRIS

MAINTAINABILITY CONSIDERATIONS

- MINIMIZE IMPACT
  - COST FOR DESIGN AND FABRICATION FOR MAINTAINABILITY
  - DOWNTIME DUE TO SHUTDOWN DURING MAINTENANCE
- FREQUENCY OF MAINTENANCE
  - UNMANNED SATELLITE
    - GENERALLY SCHEDULED, BASED ON OBSERVED DEGRADATION
    - UNSCHEDULED IN CASE OF MULTIPLE OR CATASTROPHIC FAILURES
  - MANNED SATELLITES
    - AS REQUIRED
- RELIABILITY DATA UTILIZATION IN MAINTENANCE PLANNING
- MAINTENANCE OPERATIONS COMPLEXITY
  - MAN AND EQUIPMENT LIMITATIONS
  - MAN AND EQUIPMENT POTENTIAL HAZARDS
- FAULT DETECTION AND ISOLATION
  - COMPATIBLE WITH LRU DEFINITION

ARRAY COMPONENT LIFE CONSIDERATIONS

COMPONENTS	DEGRADATION
● REFLECTORS	NEGLIGIBLE
● SOLAR CELL PANELS ● CELLS ● COVERS ● INTERCONNECTS & HARNESS ● SUBSTRATE	GRADUAL (RADIATION, THERMAL STRESS, ETC.)
● PRIMARY STRUCTURE	NEGLIGIBLE
● STRUCTURE (DEPLOY/STOW)	NEGLIGIBLE
● MECHANISMS & DRIVES	RANDOM PLUS WEAR
● SWITCHES	RANDOM
● SENSORS	RANDOM
● RADIATORS	GRADUAL (COATINGS, FLUID CORROSION, ETC.)

REPLACEMENT OPTIONS

- SOLAR CELL PANEL OR ARRAY WING MODULE
  - TOTAL REPLACEMENT AT PREDETERMINED DEGRADATION VALUE
    - AT PANEL LEVEL
    - AT WING MODULE LEVEL BY RETRACTING ARRAY AND REPLACEMENT
  - PARTIAL REPLACEMENT
    - AT PANEL LEVEL (NOT ANTICIPATED DUE TO OVERALL UNIFORM DEGRADATION)
- NON SOLAR CELL PANEL COMPONENTS
  - PREVENTIVE MAINTENANCE NOT CONTEMPLATED
    - ONLY IN CONJUNCTION WITH OTHER MAINTENANCE ACTIVITIES WHEN MONITORING INDICATES SIGNS OF INCIPIENT FAILURE

REPLACEMENT HARDWARE LOCATIONS

- UNMANNED SATELLITE - EARTH STORAGE PREFERABLE
  - MAINTENANCE REQUIRES SHUTTLE VISIT
  - REQUIRED SPARES INCLUDED IN SHUTTLE PAYLOAD
- MANNED SATELLITE - ON ORBIT STORAGE
  - SELECTED SPARES
    - RETAIN ON BOARD TO PERMIT PERIODIC MAINTENANCE BY SATELLITE CREW WITHOUT INCURRING EXPENSE OF SHUTTLE VISIT
  - ARRAY CHANGEOUT
    - UTILIZE SHUTTLE TO DELIVER REPLACEMENT ARRAY

MAINTENANCE TRADEOFF CONSIDERATIONS

- OVER-DESIGN VS MAINTENANCE
  - INITIAL ARRAY COSTS
  - MAINTENANCE COSTS
- OBSOLESCENCE DUE TO TECHNOLOGY ADVANCEMENT
  - INITIAL COSTS
  - REPLACEMENT COSTS
  - IMPROVED PERFORMANCE
- ACCEPT DEGRADATION
  - NO MAINTENANCE

RECURRING COSTS

- ARRAY FABRICATION
- ARRAY ACCEPTANCE TESTS
- QUALITY ASSURANCE SUPPORT
- MAINTENANCE
  - SHUTTLE USER FEES
  - HARDWARE REPLACEMENT COSTS

SHUTTLE PAYLOAD ACCOMMODATIONS

- SPACE SHUTTLE SYSTEM PAYLOAD ACCOMMODATIONS (JSC-07700, VOL. XIV) HIGHLIGHTS
  - MAXIMUM LAUNCH FOR 296-KM (160 N. MI.) ORBIT
    - KSC LAUNCH
      - 29484 KG FOR 28.5-DEG ORBIT INCLINATION
      - 25855 KG FOR 56-DEG ORBIT INCLINATION
    - VAFB LAUNCH
      - 16783 KG FOR 90-DEG ORBIT INCLINATION
      - 13608 KG FOR 104-DEG ORBIT INCLINATION
  - MAXIMUM PAYLOAD RETURN WEIGHT (NON-ABORT): 14,515 KG
  - MAXIMUM PAYLOAD LENGTH: 18.29 METERS
  - OMS KITS AVAILABLE FOR ADDITIONAL ΔV ARE PAYLOAD CHARGEABLE
- COSTING HIGHLIGHTS (1975 DOLLARS)*
  - MINIMUM PAYLOAD COST: $\$1.2\overline{M}$
  - DEPENDENT UPON WEIGHT LOAD OR LENGTH LOAD FACTORS
    - GOVERNMENT USE COST $= \dfrac{\text{GREATER OF TWO FACTORS}}{0.75} \times \$18\overline{M}$
    - WEIGHT FACTOR = PAYLOAD WEIGHT DIVIDED BY TOTAL PAYLOAD CAPABILITY
    - LENGTH FACTOR = PAYLOAD LENGTH PLUS 15.2 CM DIVIDED BY 1829 CM
  - EVA COST FROM \$60,000 - \$100,000 EACH
    - 2 SORTIES PER MISSION (6 HOURS MAXIMUM PER 24 HOUR PERIOD)
  - ORBIT STAY AFTER FIRST DAY: \$300,000 - \$350,000 PER DAY
  - PAYLOAD SPECIALIST TRAINING: \$75,000 - \$100,000

*STS REIMBURSEMENT GUIDE (JSC-11802); SHUTTLE EVA & DESIGN CRITERIA (JSC-10615)

ESCALATION FACTORS ASSUMED FOR 1979 DOLLARS

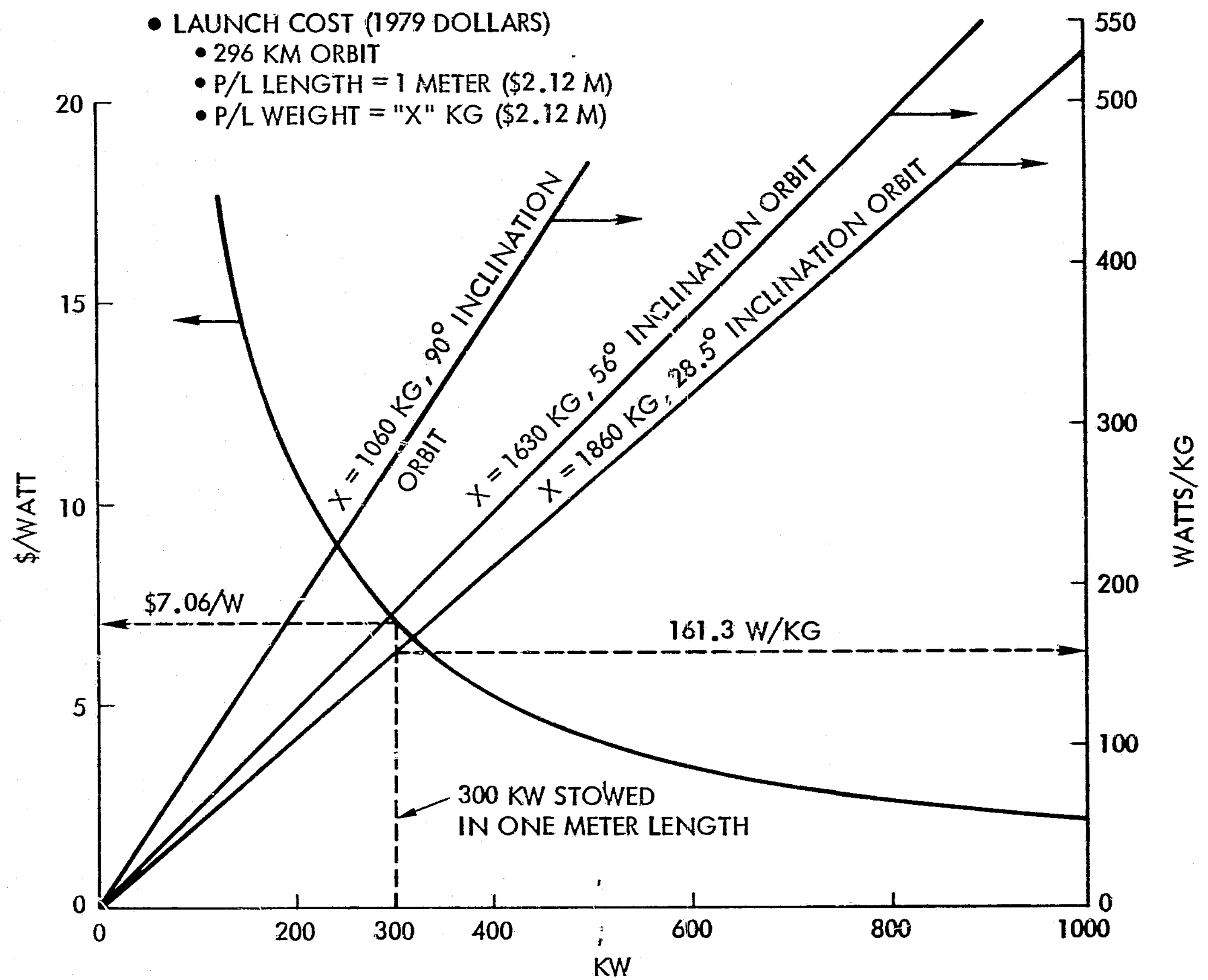
- MOST NASA COSTS ARE GIVEN IN 1975 DOLLARS
  - NASA REIMBURSEMENT GUIDE* = $1.366 \times (1.005654)^N$
- OTHER COSTS MAY BE GIVEN IN 1976, 1977, OR 1978 DOLLARS
- ROCKWELL USING SIMPLIFIED COST FACTORS AS FOLLOWS:

YEAR	ESCALATION FACTOR
1975	1.4
1976	1.3
1977	1.2
1978	1.1

* STS REIMBURSEMENT GUIDE (JSC-11802)

N = NUMBER OF MONTHS FROM OCTOBER 1978

PAYLOAD - LAUNCH COST CONSIDERATIONS

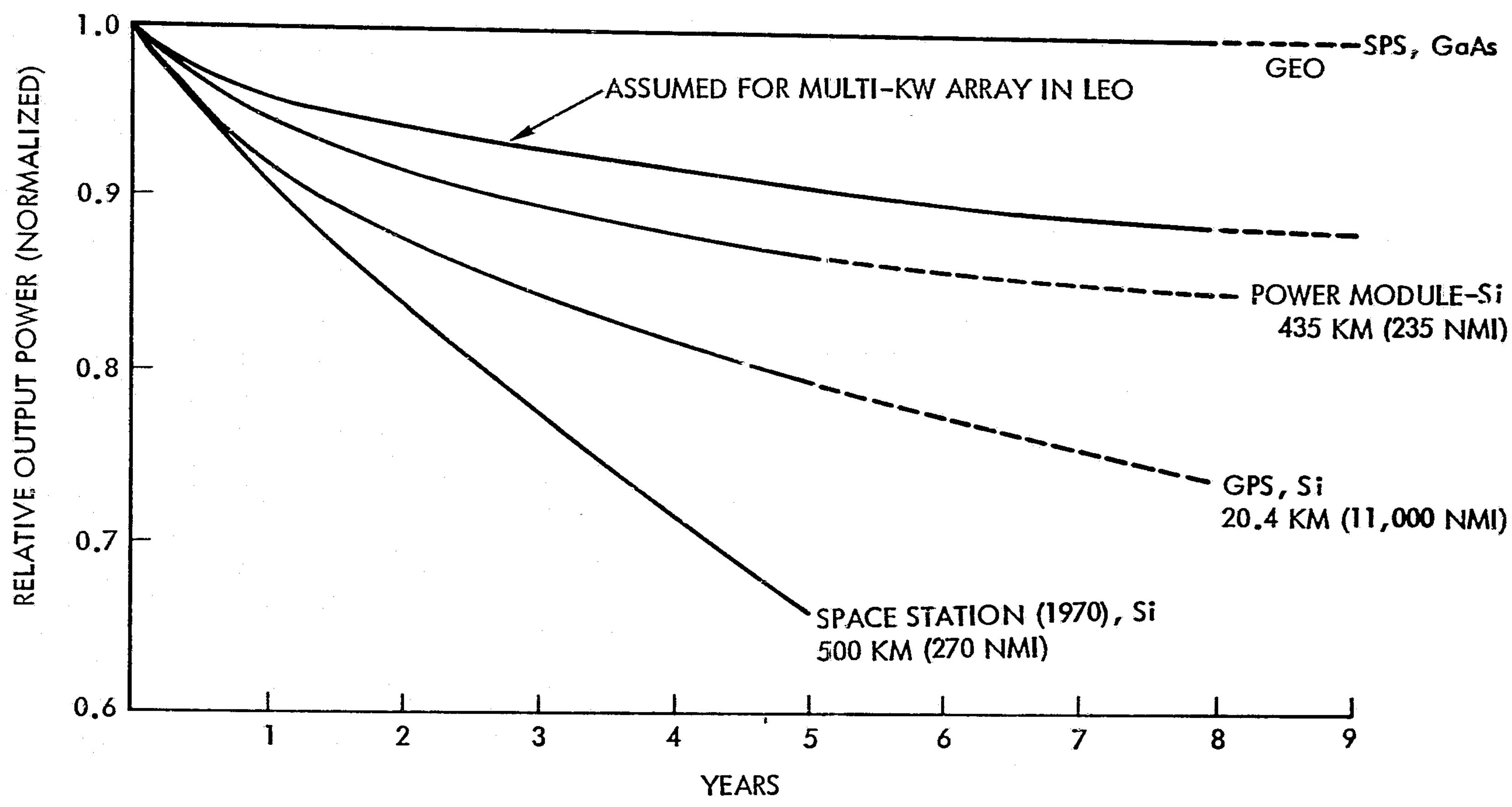


MAINTENANCE COSTS (1979 DOLLARS IN MILLIONS)

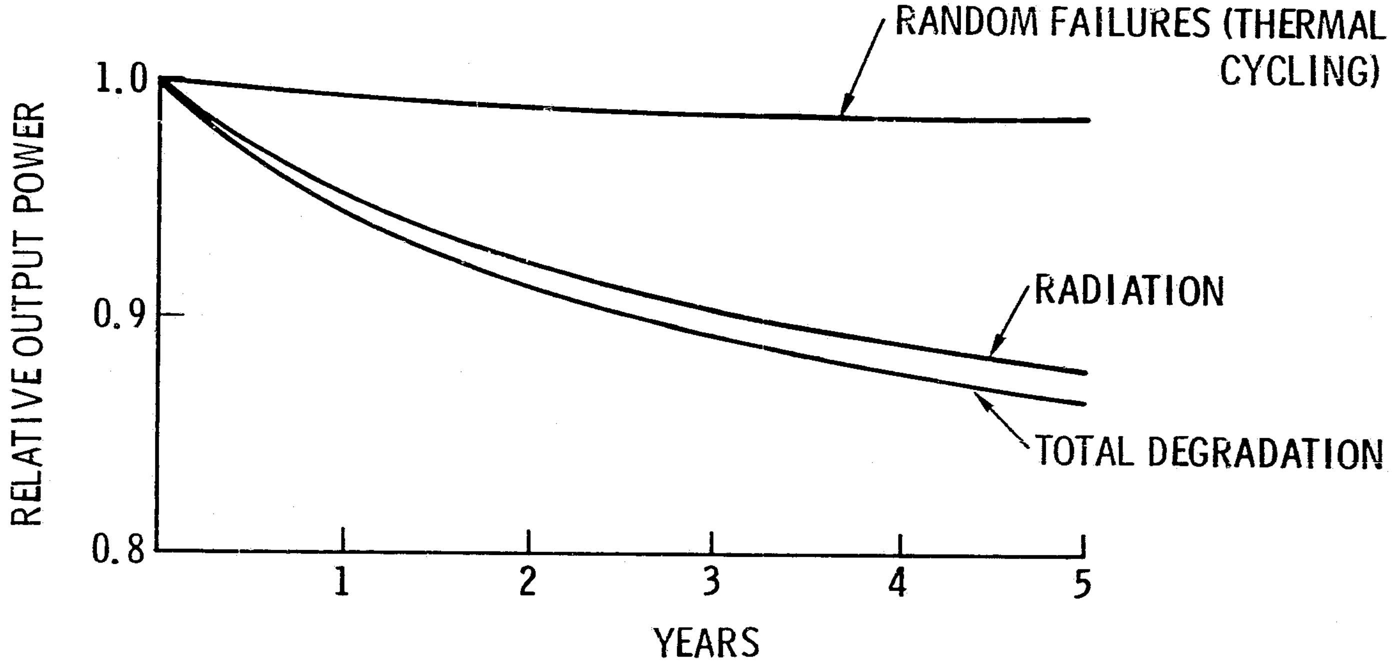
● SHUTTLE USER FEES (GOVT AGENCY RATES)	
• P/L PORTION - ASSUME 1 METER LENGTH	2.12
• EXTRA DAY IN ORBIT	0.49
• 2 EVA'S	0.28
• SPECIALIST TRAINING	0.14
TOTAL	3.03
● UNMANNED SATELLITE	
• SHUTTLE FEES (SEE ABOVE)	3.03
• REPLACEMENT SOLAR ARRAY (EXAMPLE)	5.0
TOTAL	8.03
● MANNED SATELLITE	
• SHUTTLE P/L	2.12
• 1 EVA (P/L TRANSFER)	0.14
• MAINTENANCE ACTIVITY	NO CHARGE - SATELLITE CREW
• REPLACEMENT SOLAR ARRAY	5.0
TOTAL	7.26

NOTE: SALVAGE VALUE OF RETURNED HARDWARE NOT CONSIDERED

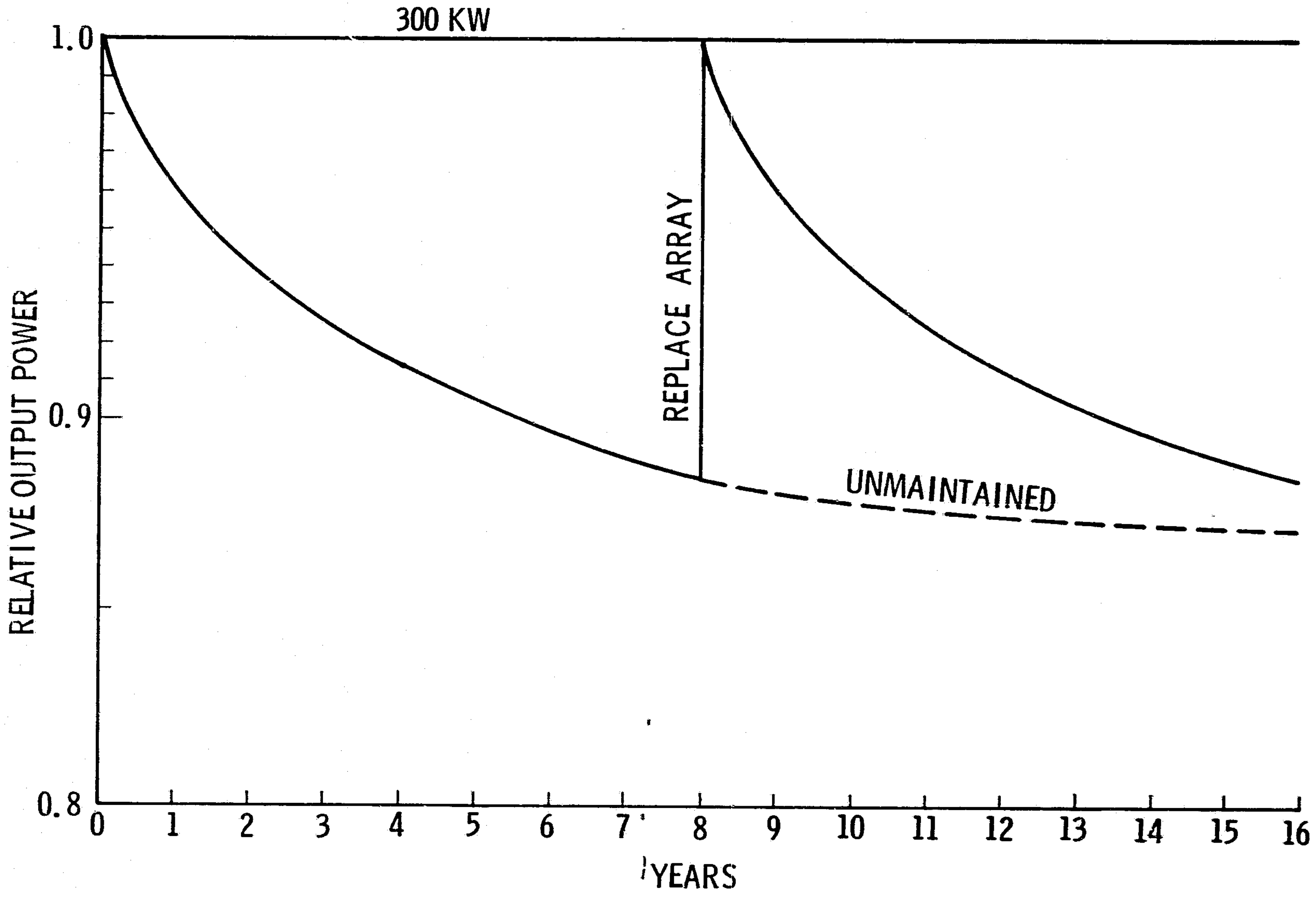
TYPICAL ARRAY DEGRADATIONS



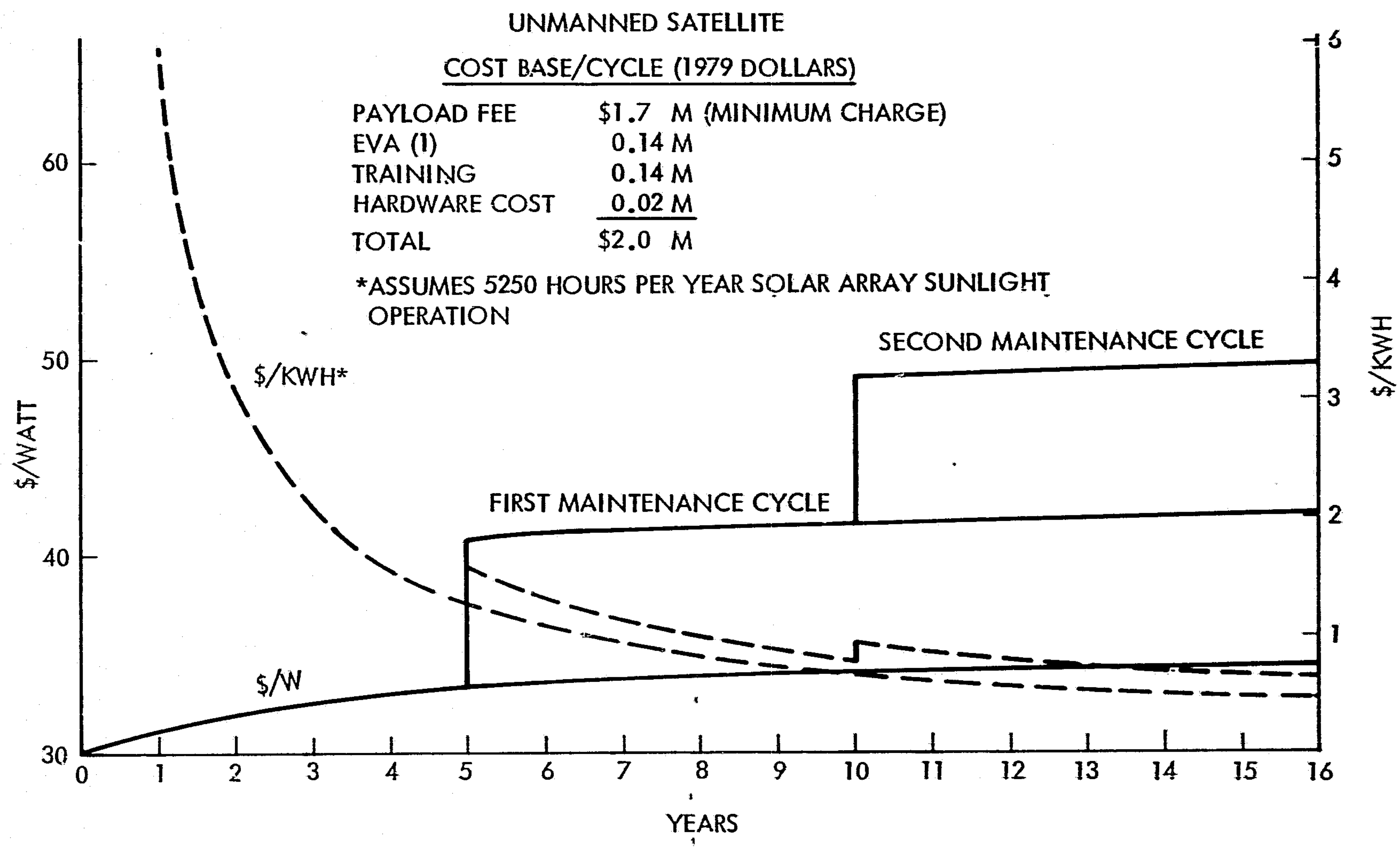
DEGRADATION ELEMENTS



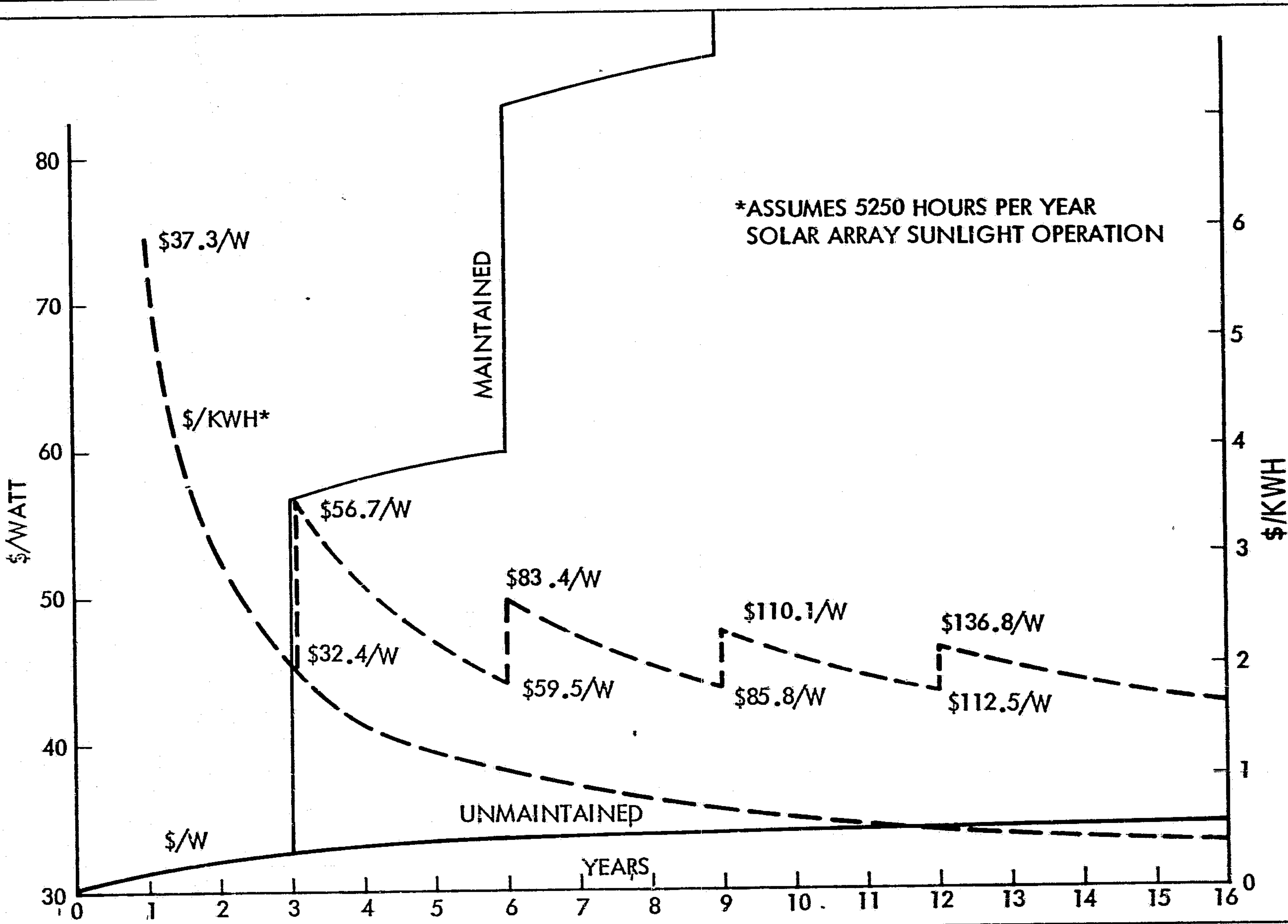
EFFECTS OF ARRAY REPLACEMENT



COST EFFECT OF MINOR MAINTENANCE



300KW ARRAY REPLACEMENT COSTS
(RECURRING)



ON-ORBIT MAINTENANCE CONCLUSIONS

- ATTAINMENT OF $30/WATT RECURRING COST DUBIOUS IF DEPENDENT ON MAINTENACE BY SHUTTLE VISITATIONS
  - MINIMUM CHARGE FOR SHUTTLE USAGE
  - MAINTAINABILITY CAPABILITY INCREASES ARRAY COMPLEXITY AND FABRICATION COST
- EXTENSION OF END-OF-LIFE APPEARS MORE COST-EFFECTIVE THAN TOTAL ARRAY CHANGEOUT
- UNMANNED SATELLITE ARRAY SHOULD INCORPORATE REDUNDANCY AND SWITCHING CAPABILITY TO MINIMIZE SHUTTLE VISITS
- MANNED SATELLITE ARRAY SHOULD INCORPORATE REDUNDANCY WITH SPARES IN SATELLITE TO BE LESS DEPENDENT ON SHUTTLE
- IF FEASIBLE, LOCATE CRITICAL COMPONENTS IN MANNED SATELLITE TO FACILITATE ANY REQUIRED REPLACEMENT
- RANDOM AND PARTIAL REPLACEMENT OF SOLAR ARRAY SECTIONS NOT ANTICIPATED BECAUSE OF EXPECTED OVERALL UNIFORM DEGRADATION CHARACTERISTIC
- DESIGNS SHOULD FEATURE INITIAL EVASION OF FAILURES
  - UTILIZE SHUTTLE CAPABILITY FOR BACK-UP TO ATTAIN ARRAY OPERATIONAL STATUS

BRIEFING OUTLINE

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–S.J. NALBANDIAN

DESIGN CONCEPTS

- SOLAR ARRAY/CELL TECHNOLOGY
  - S.J. NALBANDIAN
- CONCENTRATOR CONCEPTS
  - E.P. FRENCH
- CONFIGURATION TRADES
  - DEPLOYMENT MODES
  - PLANAR
  - CONCENTRATOR

–J.A. MENAGER

ON-ORBIT MAINTAINABILITY

- SHUTTLE CAPABILITY
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–S.J. NALBANDIAN

SUMMARY

- PRELIMINARY CONCLUSIONS
- PLANNED ACTIVITIES

–S.J. NALBANDIAN

PRELIMINARY STUDY CONCLUSION

- TO MEET \$30 PER WATT SOLAR ARRAY COST GOAL:

  <u>PLANAR</u>

  - SOLAR CELL COSTS MUST BE \$8 PER WATT - OCLI IS PROJECTING \$30/WATT FOR 5 X 5 CM CELL
  - INTEGRAL COVER CONCEPT IS NECESSARY ~\$2 PER WATT
  - TODAY'S STATE-OF-ART DEPLOYABLE MAST APPEAR AFFORDABLE AS PRIMARY STRUCTURE ~ \$12 PER WATT
  - REMAINDER OF ARRAY (SUBSTRATE) INTERCONNECTS/HARNESS/ETC.) WITHIN STATE-OF-ART ~ \$8 PER WATT

  <u>CONCENTRATOR</u>

  - "BEST BET" IS LOW CONCENTRATION; $CR \leq 5$ FOR GaAs; $CR \leq 2$ SILICON (PRIMARY JUSTIFICATION FOR HIGHER CONCENTRATION IS TODAY'S CELL COSTS)
  - ABOVE CR = 2, LIGHT PIPE BECOMES A NECESSITY
  - GaAs SOLAR CELL "BEST BET" FOR CONCENTRATION

- 100 - 300 kW PREFERRED RANGE FOR MODULES
- OVER-DESIGN FOR LONG LIFE RESULTS IN LOWER LIFE CYCLE COSTS THAN SCHEDULED MAINTENANCE
- SHUTTLE ORBITER REDUCES RECURRING COSTS WHEN UTILIZED AS BACK-UP IN DEPLOYMENT

PRELIMINARY RECOMMENDATIONS

- PLANAR CONFIGURATION
  - ASTROMAST PLANETARY DEPLOYMENT FOR PRIMARY STRUCTURE
  - FOLD UP DESIGN CONCEPT FOR BLANKET STOWAGE
  - REPLACEABLE MODULE DESIGN ($\sim$3.2 m X 3.2 m)
- CONCENTRATOR CONFIGURATION
  - ASTROMAST PLANETARY DEPLOYMENT FOR PRIMARY STRUCTURE
  - FOLD UP DESIGN CONCEPT FOR BLANKET AND REFLECTOR STOWAGE
  - LOW CONCENTRATION RATIOS OF 2-5 (TROUGH DESIGN)
  - REPLACEABLE MODULE DESIGN
- SOLAR CELL CONFIGURATION
  - LARGE AREA SILICON SOLAR CELLS ($\geq$ 25 CM^2)
  - ADVANCED GaAs THIN FILM (LARGE AREA) SOLAR CELLS FOR CONCENTRATOR CONCEPT
- MAINTENANCE
  - DESIGN FOR LONG LIFE AND NO SCHEDULED MAINTENANCE
- SOLAR ARRAY DESIGN FACTORS
  - UTILIZE SAME FACTORS AS IN TRADE-OFFS

FUTURE ACTIVITIES PLANNED

- SELECT CONCENTRATOR CONCEPT CONCENTRATION RATIO
- COMPLETE SOLAR ARRAY CONFIGURATION DEFINITION FOR PLANAR AND CONCENTRATOR CONCEPTS (~150 kW MODULES)
  - DETAIL BLANKET STACK
  - DESIGN ELECTRICAL MODULE
  - DESIGN REFLECTOR
  - DESIGN MAINTENANCE CONCEPT
- EVALUATE PERFORMANCE AND COST FOR PLANAR AND CONCENTRATOR CONFIGURATIONS
- SELECT PREFERRED CONCEPT
  - PROVIDE RATIONALE & RECOMMENDATIONS
- PREPARE FINAL REPORT

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